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LABORATORY TESTS OF RELIEF WELL FILTERS. REPORT 1. WELLS ALONG --ETC(U)
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# LABORATORY TESTS OF RELIEF WELL FILTERS. REPORT 1. WELLS ALONG MISSISSIPPI RIVER LEVEES, ALTON TO GALE, ILLINOIS

ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

MAY 1968

MISCELLANEOUS PAPER S-68-4

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Report 1

## WELLS ALONG MISSISSIPPI RIVER LEVEES ALTON TO GALE, ILLINOIS

by

F. Mitronovas

May 1968

Sponsored by

U. S. Army Engineer Division
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ARMY-MRC VICKSBURG, MISS.

# FOREWORD

The laboratory investigation reported herein was part of a broader study of relief well efficiency presently under way at the U. S. Army Engineer Waterways Experiment Station (WES) to determine causes of gradual reduction in the specific yield of the relief wells along the Mississippi River levees in the U. S. Army Engineer District, St. Louis (SLD), and to devise means to overcome this problem. The proposed plan of study includes field investigations to be conducted on selected relief wells, as well as laboratory tests to determine the performance of gravel filters placed around a well screen under controlled conditions. The laboratory test program was approved by the U. S. Army Engineer Division, Lower Mississippi Valley (LMVD), in a 1st indorsement dated 6 March 1967 to WES letter dated 20 February 1967, subject: "Well Efficiency Study."

The laboratory study was conducted under the general direction of Messrs. W. J. Turnbull, S. J. Johnson, J. R. Compton, and W. C. Sherman, Soils Division, WES. The laboratory tests were conducted by Messrs. F. Mitronovas and A. L. Sullivan, Jr. The report was prepared by Mr. Mitronovas and reviewed and approved by LMVD prior to its publication.

Director of WES during the performance of the tests reported herein and the preparation of this report was COL John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| inches | 2.54 | centimeters |
| feet | 0.3048 | meters |
| square inches | 6.4516 | square centimeters |
| liquid pints | 0.473166 | liters |
| gallons | 3.78533 | liters |
| gallons per minute | 0.06309 | liters per second |
| pounds per cubic foot | 16.0185 | kilograms per cubic meter |

## SUMMARY

Laboratory well tank tests were conducted to obtain data on the performance of gravel filters with gradations such as might result from segregation of a typical specified filter material. The tests were performed using a typical slotted wood well screen, three filter gravel gradations designated filters 1, 2, and 3, and a base material of fine, uniform Mississippi River sand. Filter 1 had the average gradation of the normally specified filter gravel for relief wells installed in the Alton to Gale, Ill., project. Filters 2 and 3 represented gradations such as might result from segregation of filter 1. The performance of the filters was evaluated by comparing their effectiveness in preventing piping of the foundation sand into the well, changes in head loss in the well screen and filter due to migration of materials, and effectiveness in preventing loss of sand and filter fines through well pipe perforations during surging. The data obtained for the purposes of filter evaluation included measurement of piezometric head distribution in foundation sand and filter gravel; hydraulic head losses in sand, gravel, and well screen; rate of sand infiltration; and loss of material into the well during surging.

It was found that no piping of foundation sand occurred through the gravel of filters 1 and 2 under the maximum hydraulic head of 8 ft applied in the tests. At the maximum head, the well discharge in the well tank tests was comparable to the maximum well flows specified in field pumping tests. The rate of sand piping through the gravel of filter 3 increased with increasing well discharge. All three filters were penetrated to varying degrees by the foundation sand during surging.

The hydraulic head losses in the screen and filter gravel for all filters were significantly less than would account for reductions in efficiency observed for wells along the Mississippi River. It is thus concluded that variation in the gradation of the filter gravel such as might be induced by segregation may lead to a failure of the well due to piping, but it is not a major factor in causing a reduction in well efficiency due to clogging of the filter gravel with foundation sand.

LABORATORY TESTS OF RELIEF WELL FILTERS

WELLS ALONG MISSISSIPPI RIVER LEVEES, ALTON TO GALE, ILLINOIS

# PART I: INTRODUCTION

## Problem

1. The relief well system along the Mississippi River levees between Alton and Gale, Ill., consists of 2029 wells installed to depths of 70 to 100 ft* and spaced on 75- to 300-ft centers parallel to the levee system. The aquifer consists almost entirely of sands and gravels. The well screens are typically from 40 to 80 ft in length and provide an effective penetration of about 50 percent. The wells are constructed of 8-in.-ID wood stave pipe risers and slotted wood stave screens wound with galvanized or stainless steel wire, with a 6-in.-thick graded gravel filter (maximum size, 1/2 to 3/4 in.) surrounding the screens. The wells were installed during the period 1953-1955.

2. At the time of installation the wells were pumped to create a drawdown of 8 ft or at a rate of 500 gpm, whichever occurred first. Pumping rates generally ranged between 6 and 12 gpm per ft of well screen. Fifteen of the wells were designated as test wells and were also subsequently pumped in 1957 and 1960. The results of these pumping tests indicated a steadily decreasing specific yield of the wells since their installation. The reduction in specific yield amounted to about 4 percent per year. It appears that the reduction might be due to clogging of the gravel filters, but the nature of the mechanism by which clogging of the gravel takes place with time has not been fully clarified as yet.

3. In general, protective gravel filters for wells in the Alton to Gale, Ill., project were designed on the basis of the following criteria:

a. To prevent movement of particles from base

$$\frac{D_{15} \text{ size of filter}}{D_{85} \text{ size of base}} \leq 5$$

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* A table of factors for converting British units of measurement to metric units is presented on page vii.

b. To prevent movement of filter fines into the screen slots

$$\frac{D_{85} \text{ size of filter}}{\text{Well screen slot width}} \geq 1.2$$

4. The validity of the design criteria has been established by both field and laboratory tests,* but a gravel filter as installed may fail to satisfy the above requirements for several reasons. In an actual installation, the gradation of a filter may differ from the design specifications due to variations in the gradation of the source material, segregation of gravel during shipment and placement around the well, or the undetected presence of foundation sand layers finer than those considered in the filter design. It was thought that such departures from specified gradations might result in clogging of the filter materials due to sand infiltration. The clogging of a filter might also be caused by silt and clay sediment carried into the well in surface water, bacterial growth, growth of algae in the filter gravel, precipitation of dissolved minerals in the groundwater, or other factors.

## Purpose and Scope

5. This investigation was undertaken to obtain data on the performance of gravel filters with gradations representing various degrees of segregation of a filter gravel having the specified gradation. The performance characteristics of such gravel filters were studied by means of laboratory well tank tests. The study included tests with three filter gravels, one of which had the standard filter gradation specified for well installations between Alton and Gale, Ill. This report describes the test equipment, procedures, and results of the investigation.

## Test Program

6. The performance of the filters was evaluated by comparing

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* U. S. Army Engineer Waterways Experiment Station, CE, "Field and Laboratory Investigation of Design Criteria for Drainage Wells," Technical Memorandum No. 195-1, Oct 1942, Vicksburg, Miss.

(a) their effectiveness in preventing piping of the foundation sand into the well, (b) changes in head loss in the well screen and filter due to migration of materials, and (c) effectiveness in preventing loss of foundation sand and filter fines through well screen slots during surging. For the purposes of the evaluation, the following data were obtained during the tests:

a. Distribution of piezometric heads in sand and filter gravel before and after surging.

b. Head losses in sand, gravel, and well screen slots for varying rates of well discharge.

c. Rate of sand infiltration and loss of material into the well during surging.

7. Only the gradation of the filter gravel was varied in these tests. The well screen and foundation sand were the same for each test. The well pipe consisted of a 2-ft length of slotted wood screen, 8-in.-ID, similar to those used in the relief well system along Mississippi River levees. The well screen was installed at the center of the tank as a fully penetrating well, flowing under artesian conditions. No attempt was made to simulate overburden stress conditions of a field installation in the tank tests. Surging of the well was performed after the flow into the tank was cut off and the water pressure in the tank reduced to the static water level a few inches above the tank lid. This is not comparable to operations in field installations, such as relief wells along the Mississippi River levees, in which the slotted portion of the well is generally 20 ft or more below the groundwater level.

## PART II: DESCRIPTION OF EQUIPMENT

### Testing Equipment

8. The apparatus used consisted of the following: a circular steel tank instrumented with piezometer tubes and containing the well screen and the materials to be tested; a large overhead tank for water supply; and a manometer board upon which piezometric waterheads within sand and gravel were read. A diagrammatic sketch of the apparatus is shown in fig. 1. The apparatus was originally designed and used to establish design criteria for drainage wells. The results of that investigation and a description of the apparatus are contained in TM 195-1.* Well tank tests were also performed at WES in connection with the design of the experimental relief well system at Trotters, Miss.** For the purposes of this investigation, the original tank was modified to accommodate a 10-1/4-in.-OD, 8-in.-ID well screen, and a new manometer board was built. The following is a detailed description of the main components of the well tank apparatus.

#### Well tank

9. The steel tank within which the well screen was installed was 5 ft in diameter and 2 ft deep. Mounted inside and concentric with the tank was a 4-ft-4-in.-diam, 60-mesh screen, which formed the outer periphery for the foundation sand. The 4-in. annular space between the screen and tank walls distributed the flow for maintaining uniform pressure conditions around the periphery of the sand. The water supply pipe leading into the tank was equipped with a baffle at the entrance into the tank. A rigid, watertight lid, with a packing collar for the well, was used to seal in the well and the materials around it. A stilling basin was provided on top of the well to provide a constant tailwater condition. The water from the stilling basin was discharged by way of a flume into a catch basin. The discharge into the catch basin was passed through a 200-mesh sieve to

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* U. S. Army Engineer Waterways Experiment Station, CE, op. cit., p. 2.

** C. I. Mansur, "Control of Underseepage by Relief Wells, Trotters, Mississippi," Technical Memorandum No. 3-341 (in 2 vols), Apr 1952, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

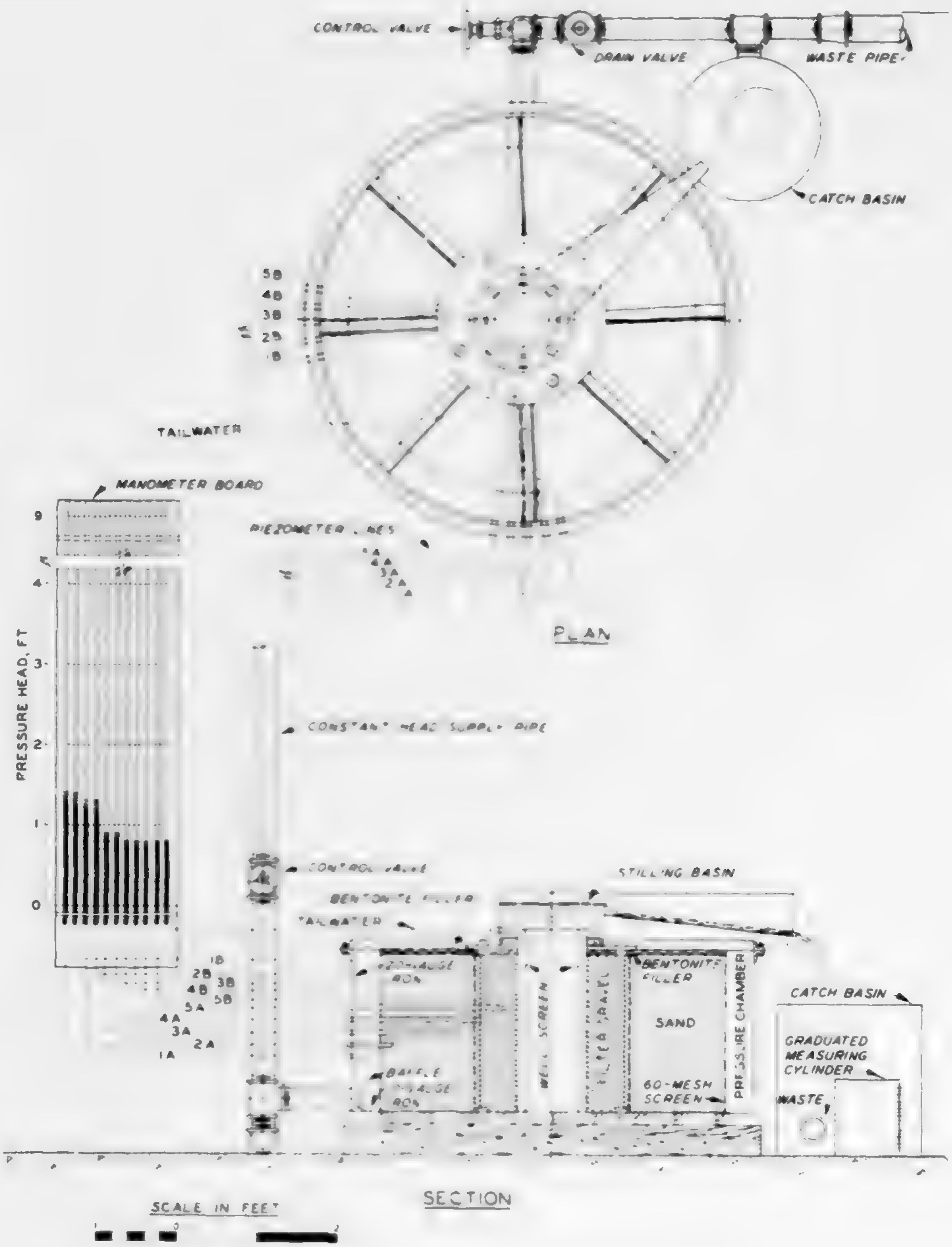



Fig. 1. Testing apparatus

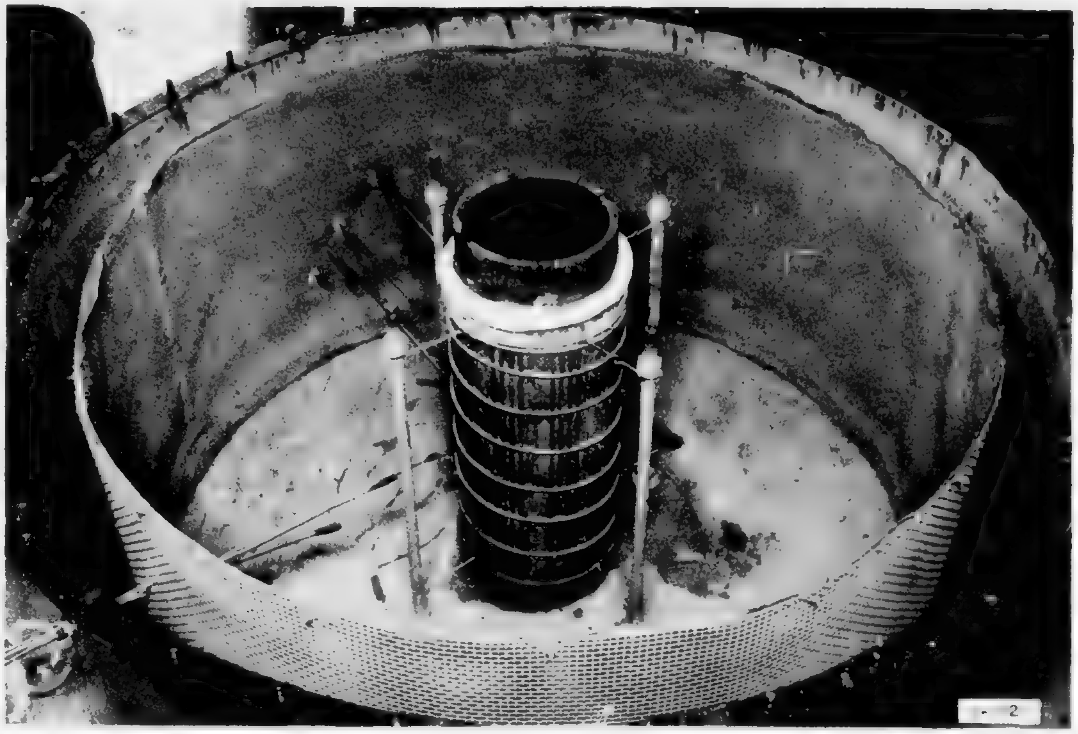



Fig. 2. Well tank with well screen and piezometers in place

remove any sand carried in suspension. Fig. 2 shows the tank interior, with piezometer tubes in place; fig. 3 shows the tank exterior.

Piezometers

10. The piezometer tubes were arranged in duplicate along two radial lines, 90 deg apart, as shown in fig. 1. The positions at which the five duplicate piezometric heads were measured were as follows: inside the gravel filter, 1-1/2 in. from the well screen and 1 in. from the sand-gravel interface; inside the foundation sand, 2 in. from the sand-gravel interface and 2 in. from the periphery; and inside the annular space. An eleventh piezometer was located inside the stilling basin to measure the tailwater level. The piezometers consisted of 1/4-in.-OD and 1/8-in.-ID copper tubing inserted into the tank and held in place by swage-lock fittings. The open ends of copper tubing inside the sand and gravel were covered with 200-mesh screen to prevent fines from entering. The


Fig. 3. Well tank in operation

piezometers were connected to the manometer board with polyvinyl chloride lines, 3/8-in.-OD and 1/4-in.-ID.

<u>Manometer board</u>

11. The manometer tubes connecting with the piezometers were mounted on a plastic-coated plywood board, approximately 1 ft wide and 10 ft long. The tubes consisted of 5/16-in.-OD and 3/16-in.-ID clear, rigid, plastic tubing arranged so that duplicate piezometers could be read on adjacent tubes. The lines connecting piezometers to the manometer tubes were slipped onto the ends of the tubing. The sliding fit was adequate to maintain a leakproof seal and required no other fastening. For deairing the piezometers, the lines were slipped off at the manometer end. The piezometric waterhead readings were estimated to the nearest 0.005 ft.

The board was mounted vertically on a wall adjacent to the tank. The maximum net waterhead that could be measured was approximately 9 ft. The lower portion of the manometer board with the tank in operation is shown in fig. 3.

Water supply tank

12. The water supply for the tests was obtained from a large overhead tank. The tank was equipped with an overflow pipe to maintain a constant water level during the flow tests. The maximum static waterhead of this tank was about 12 ft (distance from overflow pipe to tailwater at the well screen). The water pressure heads in the outer part of the well tank were controlled by a valve in the supply line.

## Well Screen

13. The well screen used in all tests consisted of nine creosoted wood staves, bound with steel wire. The inside diameter of the well screen was 8 in.; the wall thickness was 1-1/8 in. The overall length of the slotted portion of the well screen was 2 ft. The screen contained 108 longitudinal slots, 3-1/4 in. long and 3/16 in. wide (slots uniform in width, nontapered), with a total slot area of 65.8 sq in. or 8.5 percent of the outside area of the pipe. The bottom of the pipe was plugged with a tight-fitting disk, about 1 in. thick. The unobstructed slotted length of the pipe was 22 in. (1.83 ft), allowing 1 in. for the bentonite seal.

PART III: TEST PROCEDURES

## Materials Tested

14. The gradations of the foundation sand and three filter gravels tested are shown in fig. 4. The densities and grain-size characteristics

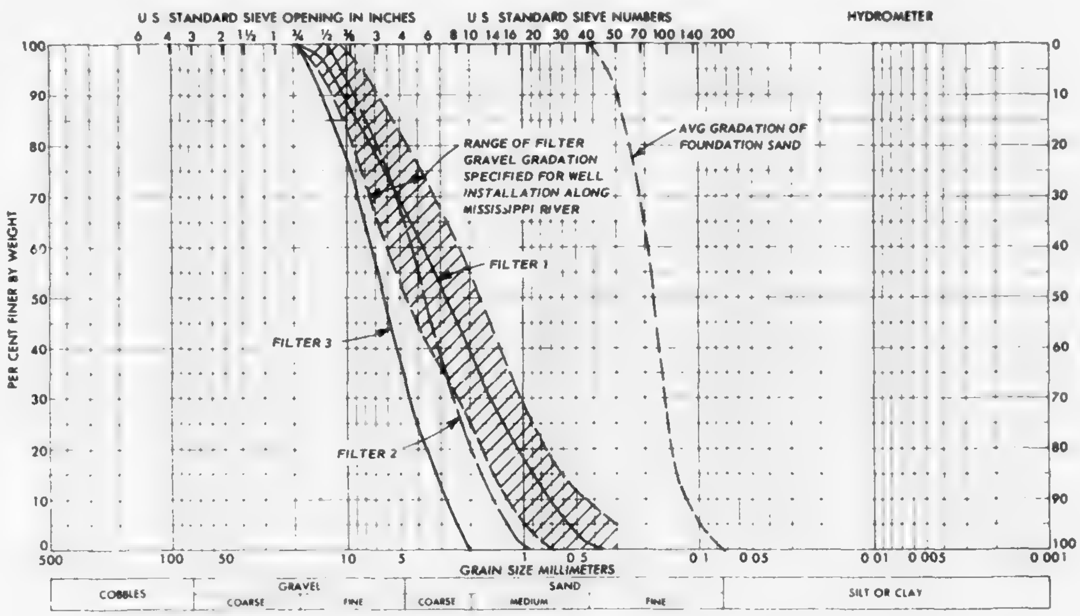



Fig. 4. Gradation of filter gravel and foundation sand

of the materials as placed in the tank are given in table 1. The foundation material was a fine, uniform Mississippi River sand. Filter 1 represents the average gradation of the filter gravel range specified for relief well installations along the Mississippi River. Filters 2 and 3 represent gradations of filters that might be developed if there were segregation of filter 1. Filters 2 and 3 are the coarse fractions of filter 1 obtained by scalping the 15 and 40 percent finer sizes from filter 1, respectively. The filter gravels were prepared by sieving a quantity of alluvial gravel into fractions and recombining these as needed to give the required gradation.

## Method of Placement of Materials

15. The sand and gravel for each test were placed around the well screen under water, in layers about 2 in. thick. A sheet-metal form, 12 in. high and 23 in. in diameter, positioned concentric with the well screen, was used for placing filter gravel. The foundation sand was raked by hand as it was placed to eliminate entrapped air. No other compaction was employed. The filter gravel was rodded lightly as it was placed. When the sand and gravel reached a depth of about 1 ft, the metal form was removed, and the piezometer tips were placed in position. As each piezometer was set, the metal form was replaced, and placing of sand and gravel was resumed. When the level of the sand and gravel was about 1 in. from the top of the tank, the metal form around the gravel was removed, and the water level in the tank was lowered about 1/2 in. below the surface of the sand. A dry mixture of sand-bentonite, with bentonite about 15 percent by weight, was prepared and placed over the sand and gravel even with the top of the tank. Then the water level in the tank was raised to the top of the tank, and a rigid, watertight lid was bolted on. The tank, with the materials and the lid in place, was allowed to stand overnight to permit the bentonite to swell and form an impervious seal beneath the lid. Relief valves on top of the lid were opened to permit entrapped air to escape as the bentonite swelled.

## Testing Sequence

16. After the tank was sealed, the pressure head at the outer circumference of the sand foundation was raised to an initial net head of 0.5 ft of water and maintained for about 1/2 hr to permit the flow to stabilize. In the meantime, the piezometer lines were cleared of entrapped air by applying vacuum and bleeding the lines. At the end of the 1/2-hr interval, the flow into the well was measured by timing the discharge into a 6-gal container. The piezometric heads were then read on the manometer board. This procedure was then repeated with net pressure heads of 1.0, 1.5, 2.0, 3.0, 4.0, and 5.0 ft of water. These pressure heads were

maintained for about 10 to 15 min before measuring discharge. The inwash of sand through the well screen was checked continuously by observing the bottom of the well as lighted with a flashlight. Any material washed in was collected for weighing. After the test under the 5-ft head was completed, the pressure heads were decreased to 4.0, 3.0, 2.0, 1.5, and 0.5 ft of water and the tests repeated.

17. At the completion of the cycle of pressure tests, the flow into the well was cut off and the well was surged with 50 plunger strokes in increments of 10 strokes, each stroke consisting of an up-and-down round trip. The plunger consisted of a 7-in.-diam rubber disk mounted between two 6-in.-diam steel plates. The plunger strokes were applied manually with rapid up-and-down movements. The water level in the well during surging was kept a few inches above the tank lid. At the end of each 10-stroke increment, the depth of material in the well was measured by sounding with a rod. The soundings were taken at the center of the well and at four 90-deg positions along the periphery. An average of the five readings was considered to be the depth of material in the well. The material was then recovered from the bottom of the well and weighed, and its volume and gradation were determined. At the end of a 50-stroke surging cycle, the tank was tested under a low pressure head to determine if the bentonite seal held. If the seal was intact after surging, the sequence of pressure heads applied before surging was repeated.

18. After the first surging cycle, the bentonite seal failed on filters 1 and 2, apparently as a result of the relatively large volume of material washing into the well and also possibly due to some densification and settling of the foundation sand. On filter 3, the bentonite seal failed after 20 strokes of the first surging cycle. No further tests were performed on filter 3 following the surging because the foundation sand became completely unstable during the initial surging strokes. When the seal failed on filters 1 and 2, the tank lid was removed and the bentonite replaced. In tests of filter 1, the seal held after the second, third, and fourth surging cycles. After the third surging cycle, tests of filters 1 and 2 were increased to net pressures of 8.0 ft of water. No further flow tests were performed on filters 1 and 2 after the fourth cycle of surging.

Fig. 5. Well tank at conclusion of test with filter 2

Fig. 5 shows the condition of filter 2 around the well screen after the fourth surging cycle.

19. At the conclusion of all testing and surging with each filter gravel, the tank was drained and the sand and gravel were removed. First, the tank lid was unbolted and the bentonite seal removed. With filters 2 and 3, in-place densities were obtained by taking four samples in the upper half of the foundation sand in the tank and four in the lower half. The samples were taken with a 2-in.-ID piston sampler. The in-place density of sand with filter 1 and each of the filter gravels was computed from the dry weights of these materials obtained during their placement in the tank.

20. Then, with the well screen still in place, the sand and gravel around the well were removed from the tank by excavating with shovels. The foundation sand was stored in a moist condition on the concrete floor adjacent to the tank to be reused in the next test. During the removal of the filter gravel, four samples were taken for sieve analyses. Two of these

samples were obtained adjacent to the well screen (within approximately 2 in.), and two more adjacent to the sand-gravel interface. Sieve analyses were performed on representative portions of these samples.

21. After the tank was emptied and cleaned, the lid was replaced, and with the well screen in place, flow tests were performed to determine head loss through the gravel-clogged screen slots. The sand and gravel that had become lodged in the screen slots in the course of surging and testing were retained undisturbed during these tests. At the conclusion of a test, the well screen was removed from the tank, and the gravel-clogged screen slots were photographed. The photographs were taken using a lighted electric light bulb suspended inside the well screen to provide contrast between plugged portions of well screen and open slot areas. The sand and gravel were removed from the screen slots before the well was used in the next test.

PART IV: TEST RESULTS

## Well Flows and Head Losses

22. The data on well flows and head losses obtained during all tests are summarized in table 2. The head losses were computed by subtracting the tailwater manometer readings from the readings at each piezometer position, and represent an average of two readings obtained from the duplicate piezometers. The discharge per foot of well screen was obtained by dividing the total discharge by the unobstructed well screen height of 1.83 ft. At the maximum head, the well discharge in the well tank tests was comparable to the maximum well flows specified in field pumping tests for wells installed in the Alton to Gale, Ill., project.

### Head losses through filter

23. The distribution of head loss in the foundation sand and gravel filter is shown on semilogarithmic plots of head versus radial distance from center of well screen. The results from all tests with filters 1, 2, and 3 are shown in plates 1 through 3. The plotted points and the numbers by the curves indicating discharges represent an average of two readings obtained at each head, except in the case of filter 1 before surging where they represent the final reading at each head.

24. Fig. 6 shows a comparison of head loss distribution within filters 1, 2, and 3 before and after surging at a discharge of 5 gpm per ft of well screen (filter 3 was not surged a complete cycle). For the respective heads, the head loss in the foundation sand was approximately the same for all three filters before surging. The head loss in the gravel was about 2.9 percent of the applied net head for filter 1 before surging, and about 3.2 percent after surging. With filter 2, the head loss was about 0.9 percent before surging and 1.3 percent after surging. With filter 3, the head loss in the gravel increased to about 9 percent after foundation sand began piping through the gravel.

25. As shown in fig. 6, a redistribution of head loss occurred in filters 1 and 2 as a result of surging and in filter 3 as a result of sand infiltration by piping. After surging, the hydraulic gradient in the

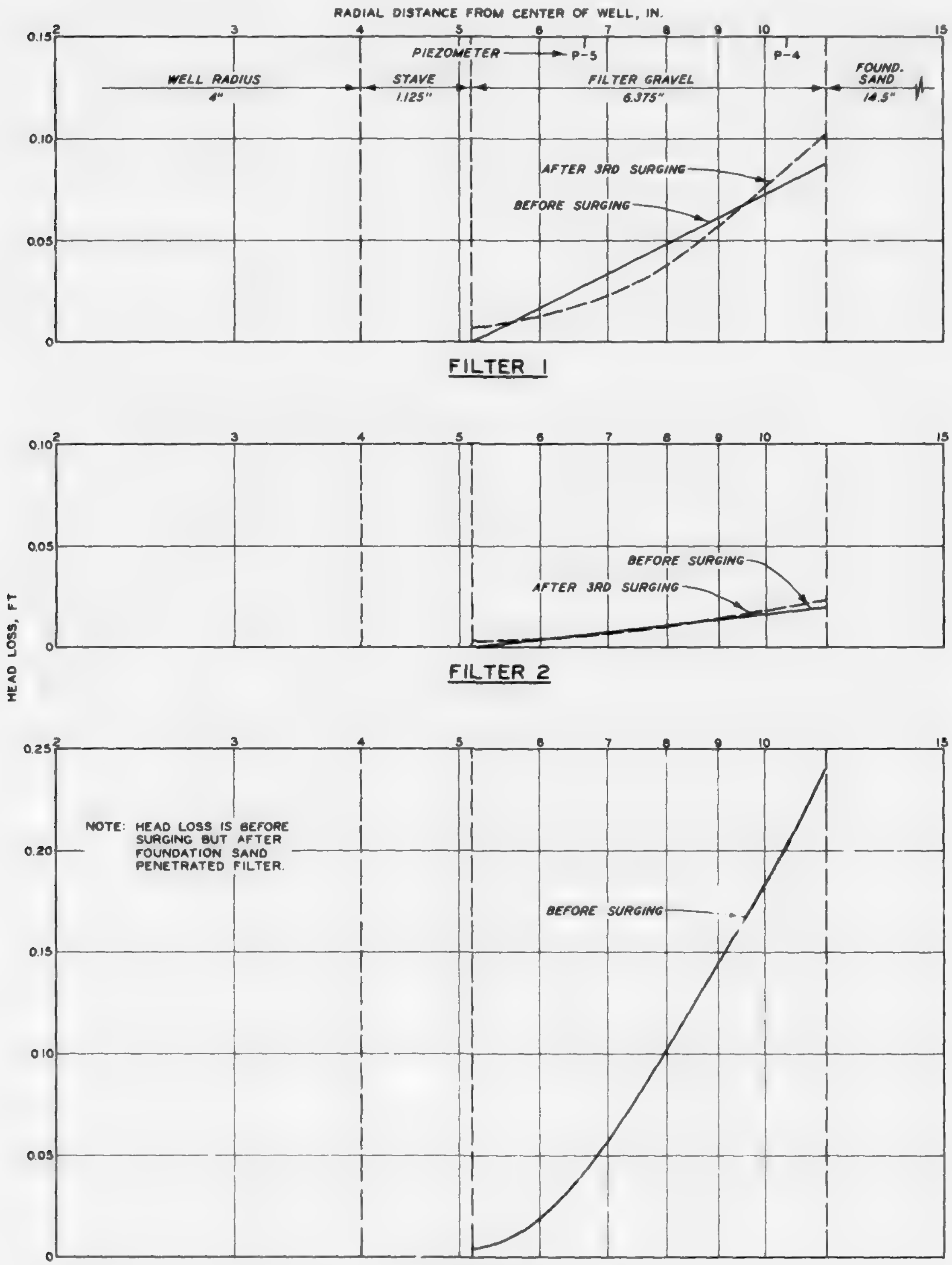



Fig. 6. Comparison of head loss distribution at a discharge of 5 gpm per ft of well screen before and after surging

filter gravel increased somewhat at the sand-gravel interface, presumably due to movement of fines into the filter. At the same time, the gradient was reduced near the well screen as a result of loss of fines into the well during surging.

26. The coefficients of permeability computed for the foundation sand and the gravels of filters 1, 2, and 3 are shown in plates 4 through 7 and are plotted against $D_{10}$ grain size in fig. 7. The $D_{10}$ grain size of filter gravel after surging is that shown in figs. 10, 11, and 12 (pages 20, 22, and 23) for filters 1, 2, and 3, respectively, adjacent to foundation sand. The range of computed permeabilities for sand and filters 1 and 2 is within the limits predicted by the Hazen formula, $k = C(D_{10})^2$ . For filter 3, the computed permeability is based on the initial straight portion of the head loss versus well discharge curve, and the correlation with $D_{10}$ grain size does not agree with the Hazen formula.

27. Plots of well discharge versus head loss between piezometers in sand are shown in plates 4 through 7. After surging, the head loss at a given discharge increased about 10 percent with filter 1 and decreased about 10 percent with filters 2 and 3. The decrease in the net applied head with filters 2 and 3 may be due to redistribution of piezometric head in the sand adjacent to the filter gravel.

28. Plots of well discharge versus head loss between piezometers in filter gravel are also shown in plates 4 through 7. The increase in head loss after surging of filters 1 and 2 resulted from the infiltration of foundation sand during surging and in filter 3 from infiltration of sand by piping during flow tests. For filter 3, the head loss versus discharge curves become nonlinear at flows above 3 gpm per ft of well screen, indicating an unstable condition of the foundation sands at higher flows.

Head losses through screen

29. Measured data on the head loss through the gravel-clogged well screen slots with the filter gravel and sand removed are summarized in table 3, and a plot of well discharge versus head loss through the gravel-clogged screen is shown in plate 7. The percentages of unclogged slot areas indicated in table 3 were estimated from the photographs in fig. 8,

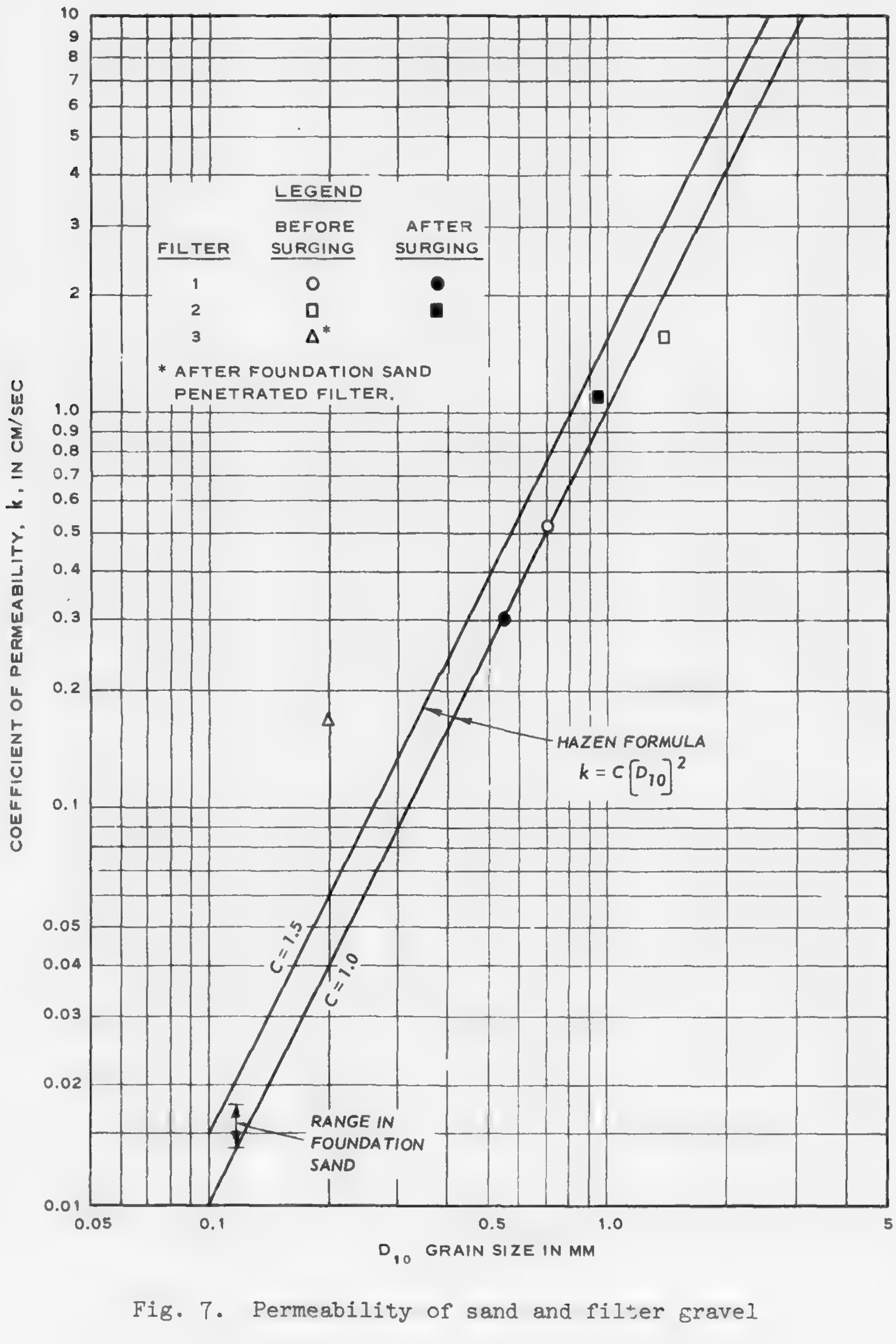
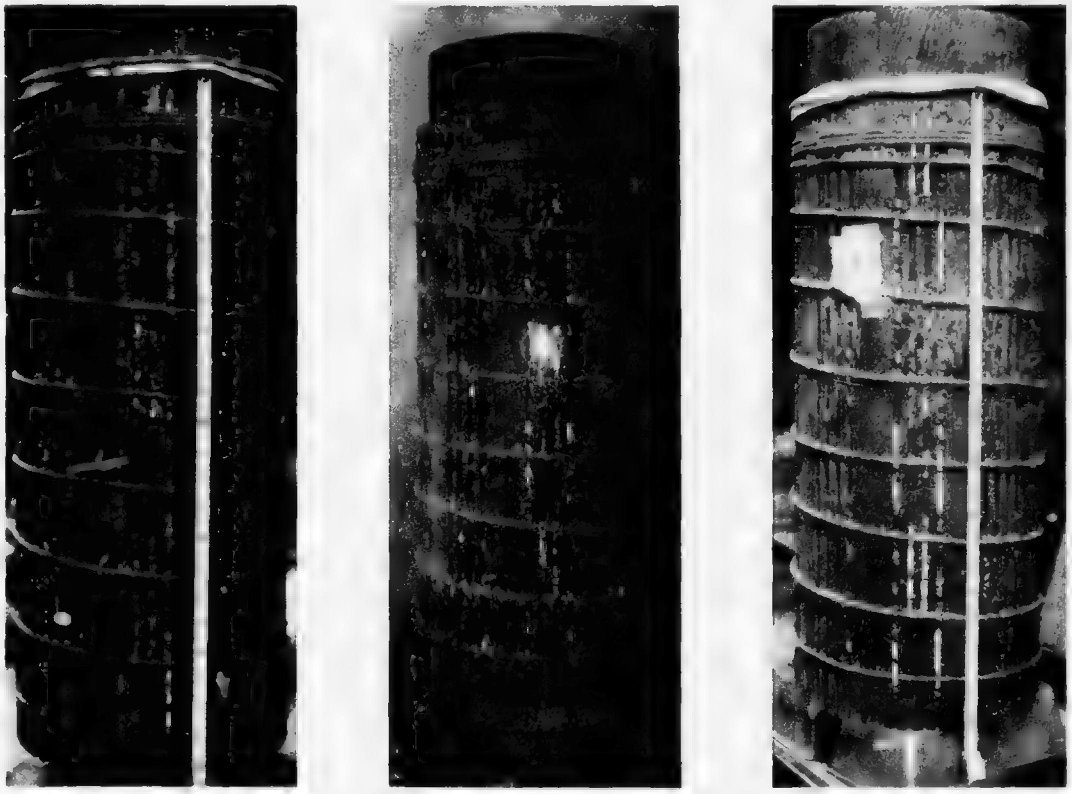



Fig. 7. Permeability of sand and filter gravel



a. FILTER 1 b. FILTER 2 c. FILTER 3

Fig. 8. Clogging of well screen with filters 1, 2, and 3

which show the extent to which the well screen was clogged by filters 1, 2, and 3 at the end of all testing and surging.

## Analysis of Material Removed by Surging

30. Measurements of the quantity of material removed by surging are summarized in table 4. The volume of surged material in the well after each surging cycle for filters 1, 2, and 3 is plotted in fig. 9. On the basis of fig. 9, it appears that filters 1 and 2 would reach stable conditions, with progressively smaller amounts of sand and gravel coming through the screen slots if surging had been continued. The foundation sand with filter 3 was completely unstable under the surging action of the first few

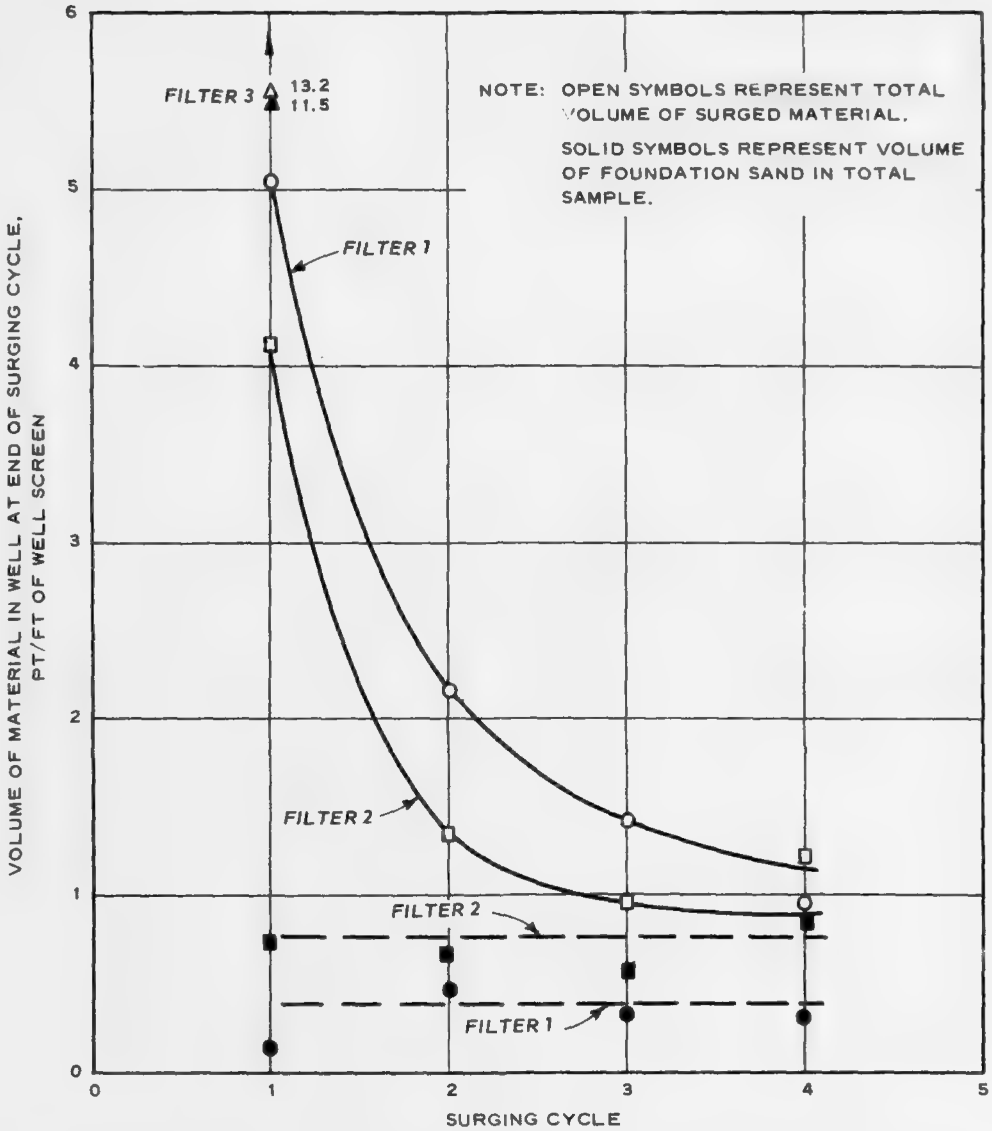



Fig. 9. Volume of material in well versus surging cycle

surging strokes, and the first surging cycle was not completed.

31. A summary of gradation of surged material for filter 1 is shown in fig. 10. The gradation curves for the surged material show progressively higher percentages of sand in the material with increasing number of surging cycles. The filter gravel around the well screen at the conclusion of the test showed a loss of some fines adjacent to the well screen and

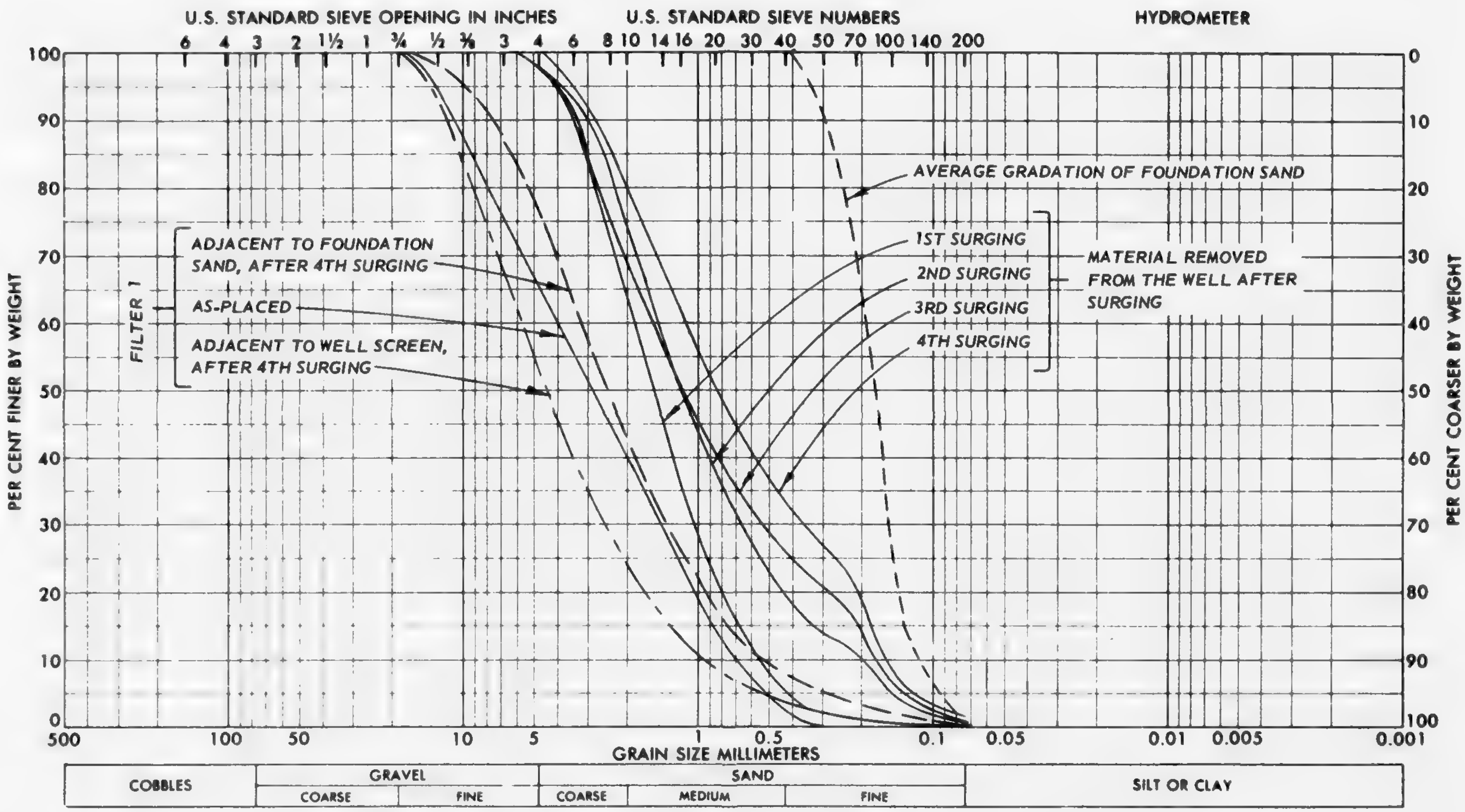



Fig. 10. Summary of gradation of surged material and filter 1

infiltration by foundation sand near the sand-gravel boundary. Since no sand was piped through the filter gravel while the well was discharging, the infiltration of foundation sand into the gravel near the boundary is probably due entirely to surging.

32. A summary of gradation of surged material for filter 2 is shown in fig. 11. By comparison with filter 1, the proportion of sand in surged material is greater for filter 2, as shown by the progressively higher percentages of sand in the surged material. Filter 2 lost fewer fines adjacent to the well screen, but the amount of sand in the gravel adjacent to the sand-gravel boundary increased.

33. A summary of gradation of surged material for filter 3 is shown in fig. 12. The surged material was predominantly sand, with little loss of gravel. The presence of sand in the filter adjacent to the well screen as well as near the boundary indicates that foundation sand had completely penetrated the filter gravel during surging.

34. The rate at which the foundation sand was piped through the gravel of filter 3 is shown in fig. 13, with the test results summarized in table 5. Fig. 13 shows a straight line relation on a semilogarithmic graph between the rate of sand infiltration and the estimated hydraulic gradient in the gravel at the sand-gravel interface. The duration of the infiltration tests varied from 5 to 15 min. The duration of these tests was kept short to avoid a rapid failure in the bentonite seal due to loss of sand from the tank.

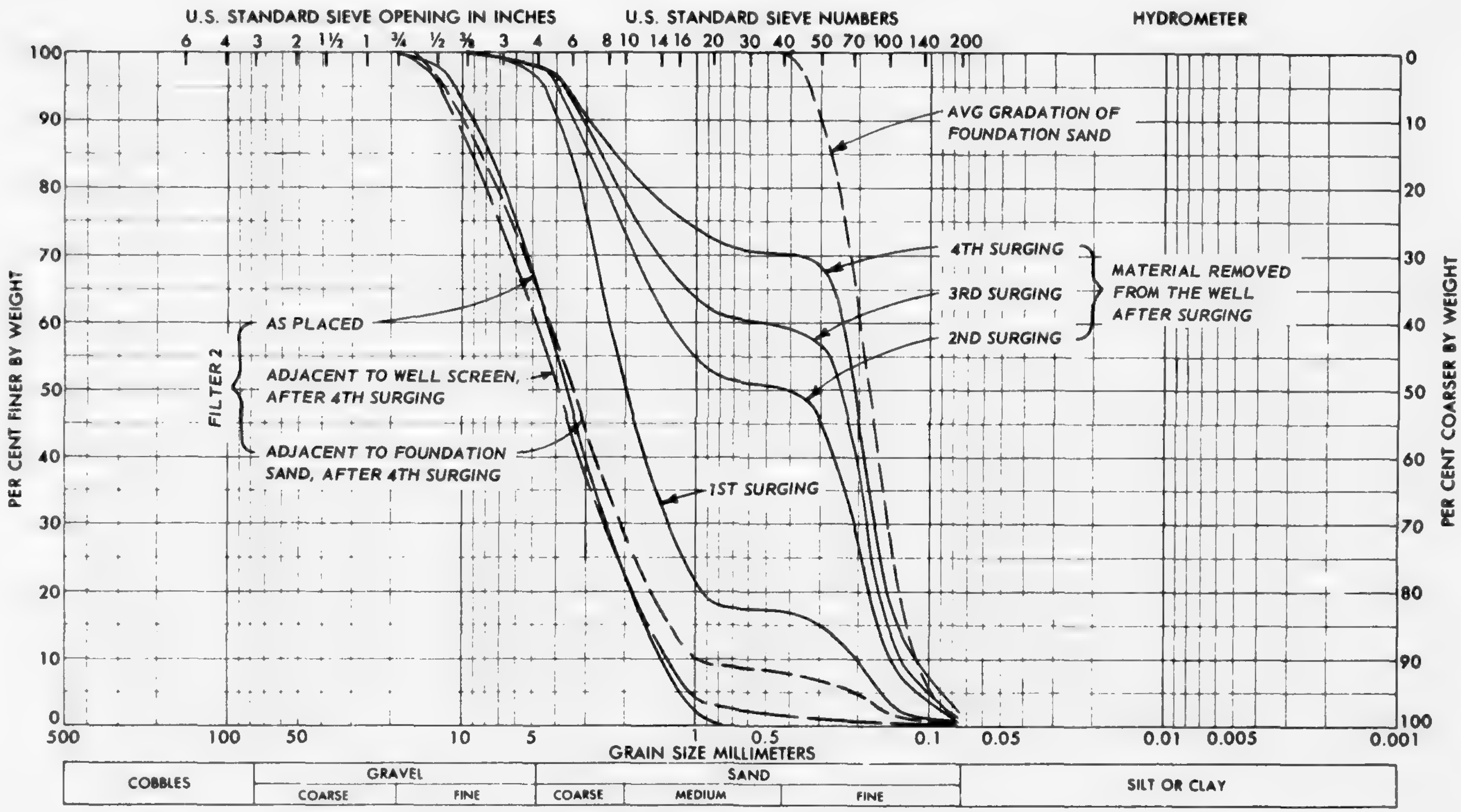



Fig. 11. Summary of gradation of surged material and filter 2

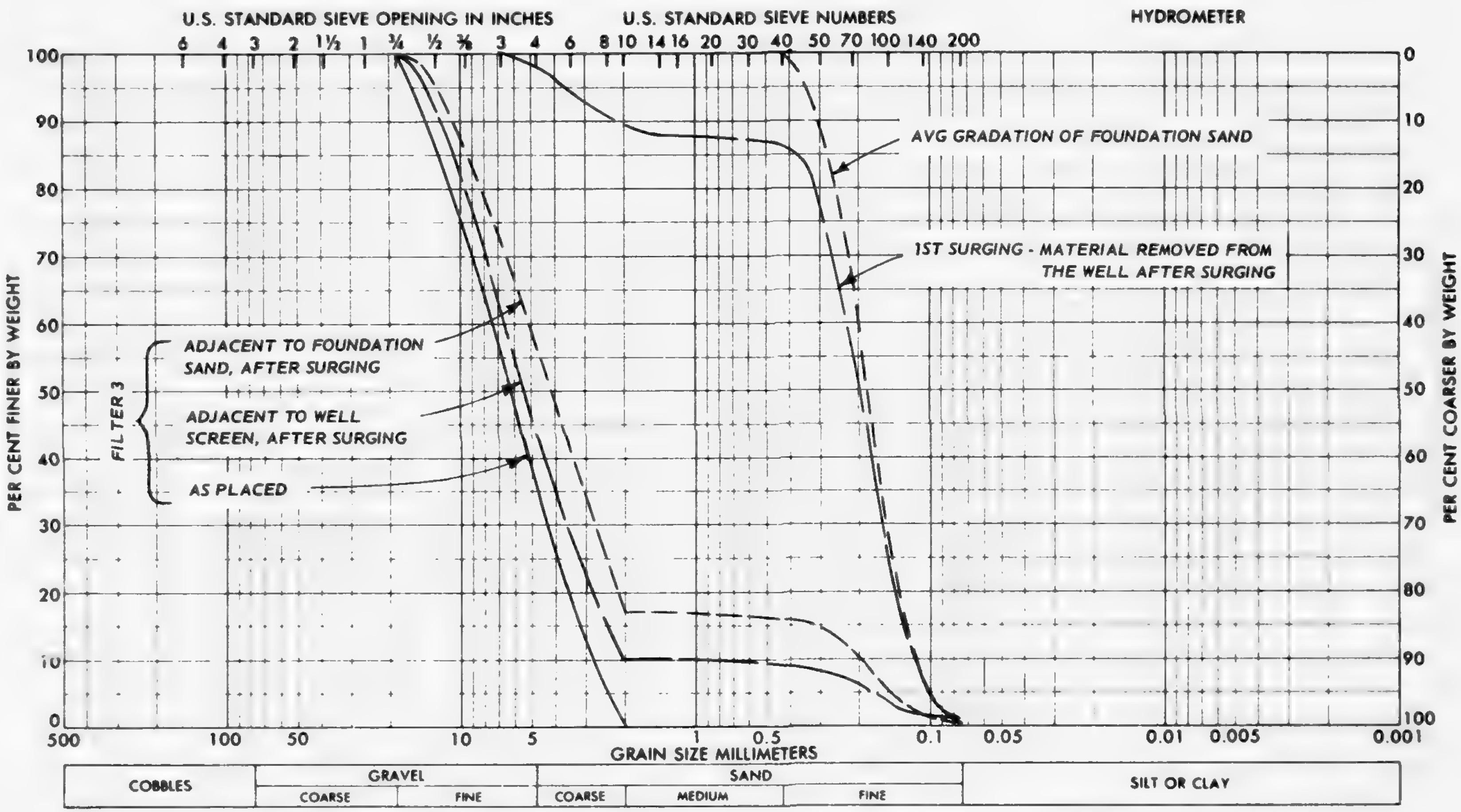



Fig. 12. Summary of gradation of surged material and filter 3

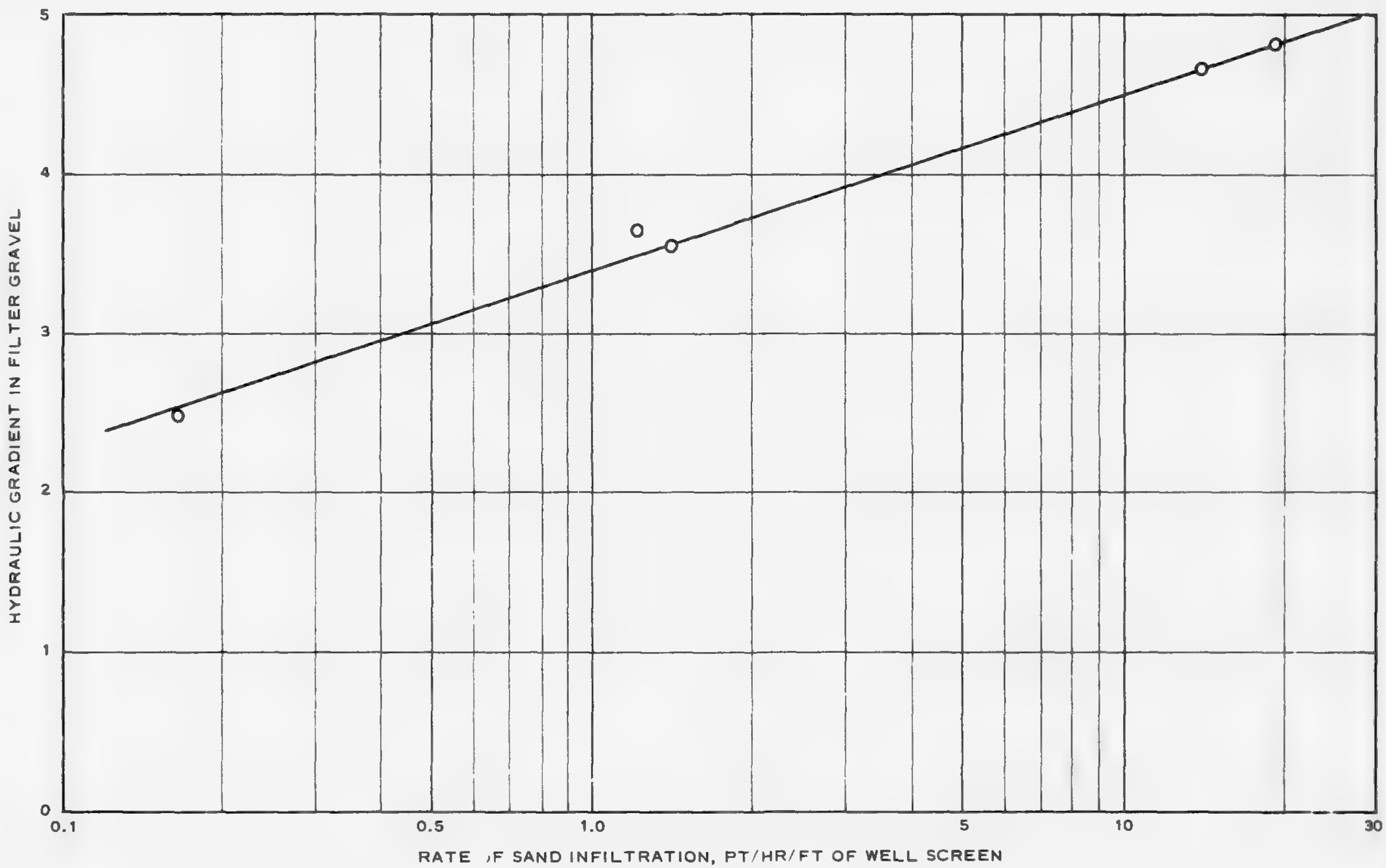



Fig. 13. Rate of sand infiltration through filter 3

## PART V: SUMMARY AND CONCLUSIONS

### Summary

35. As a result of the investigation reported herein, the following observations were made:

- a. No piping of foundation sand occurred through the gravel of filters 1 and 2 under the hydraulic heads applied in these tests. The rate of sand piping through the gravel of filter 3 increased with increasing well discharge.
- b. All three filters were penetrated by the foundation sand during surging. The amounts of sand entering the well were greatest with filter 3. The proportions of sand in the surged material increased with successive surging cycles for filters 1 and 2.
- c. The volume of material entering the well during successive surging cycles decreased with filters 1 and 2, indicating that these filters would reach stable condition if surged further. The foundation sand with filter 3 was completely unstable under the first few surging strokes.
- d. Redistribution of head losses occurred in filters 1 and 2 after surging and in filter 3 after sand began piping through the gravel. With filters 2 and 3, redistribution of head losses also occurred in the foundation sand near the sand-gravel boundary.
- e. Before surging, the discharge with all three filters was about the same. After surging, the net applied head increased about 10 percent with filter 1 and decreased about the same amount with filters 2 and 3 at equal discharge. The decrease in the net applied head with filters 2 and 3 was probably due to a redistribution of head loss in filter gravel and in sand near the sand-gravel interface.

### Conclusions

36. On the basis of the test results reported in this study, the following conclusions are presented:

- a. The average gradation of filter gravel (filter 1) typically specified for slotted wood screen relief wells along the Mississippi River, if properly placed to minimize segregation, will function effectively as a filter with a minimum of head loss in the filter gravel and screen.

b. Should the filter gravel be placed so that segregation occurs, foundation sands will migrate into and through the coarser zones of the filter gravel, decreasing the permeability of the filter and possibly causing failure of the well due to piping.

c. The maximum clogging of screen slots and, consequently, the highest screen loss were measured for filter 1. The screen losses and head losses in the filter gravel for all filters were significantly less than would account for reductions in well efficiency observed for wells along the Mississippi River, and thus it is concluded that variation in the gradation of the filter gravel such as might be induced by segregation is not a major factor in causing a reduction in well efficiency.

Table 1

Initial Grain Size and Density Characteristics of Foundation Sand and Filters

| Size or Characteristic | Foundation Sand | Filter Gravel: Filter 1 | Filter Gravel: Filter 2 | Filter Gravel: Filter 3 |
|---|---|---|---|---|
| $D_{10}$ size, mm | 0.12 | 0.64 | 1.3 | 2.5 |
| $D_{60}$ size, mm | 0.20 | 3.7 | 4.2 | 7.2 |
| Coefficient of uniformity, $C_u$ | 1.7 | 5.8 | 3.2 | 2.9 |
| $D_{15}$ size, mm | 0.13 | 0.8 | 1.5 | 2.9 |
| $D_{85}$ size, mm | 0.27 | 8.9 | 8.2 | 10.2 |
| $\frac{D_{15}\text{ filter}}{D_{85}\text{ base}}$ | | 3.0 | 5.6 | 10.8 |
| Void ratio, $e_o$ | 0.66 | 0.50 | 0.58 | 0.66 |
| Average in-place dry density, pcf | 101.3 | 112.1 | 106.5 | 101.7 |
| Relative density | | | | |
| $\frac{\gamma - \gamma_{min}}{\gamma_{max} - \gamma_{min}}$, % | 66 | 46 | 50 | 60 |
| Minimum dry density, pcf | 89.6 | 102.0 | 98.6 | 92.7 |
| Maximum dry density, pcf | 107.3 | 124.1 | 114.6 | 107.6 |

Table 2

Summary of Well Flow and Piezometric Data

| Step | Before Surging | | | | | | | After 1st Surging | | | | | | | After 2d Surging | | | | | | | After 3d Surging | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Piezometric Head, ft | | | | | Discharge gpm | | Piezometric Head, ft | | | | | Discharge gpm | | Piezometric Head, ft | | | | | Discharge gpm | | Piezometric Head, ft | | | | | Discharge gpm | |
| | $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ | Total | Per ft Screen | $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ | Total | Per ft Screen | $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ | Total | Per ft Screen | $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ | Total | Per ft Screen |
| | | | | | | | | | | | | | Filter 1 | | | | | | | | | | | | | | | |
| 1 | 0.50 | 0.46 | 0.11 | 0.02 | 0.01 | 1.86 | 1.03 | 0.50 | 0.45 | 0.12 | 0.02 | 0.01 | 1.40 | 0.77 | 0.50 | 0.44 | 0.11 | 0.02 | 0.01 | 1.40 | 0.77 | 0.50 | 0.42 | 0.10 | 0.01 | 0 | 1.39 | 0.76 |
| 2 | 1.01 | [illegible] | 0.23 | [illegible] | 0.02 | [illegible] | [illegible] | 1.00 | 0.90 | 0.22 | 0.02 | 0.01 | 2.84 | 1.55 | 1.00 | 0.90 | 0.22 | 0.03 | 0.01 | 2.81 | 1.54 | 1.00 | 0.87 | 0.21 | 0.03 | 0.01 | 2.79 | 1.52 |
| 3 | 1.50 | 1.39 | 0.34 | [illegible] | 0.02 | [illegible] | 2.84 | 1.50 | 1.36 | 0.34 | 0.04 | 0.01 | 4.24 | 2.31 | 1.50 | 1.34 | 0.32 | 0.04 | 0 | 4.24 | 2.31 | 1.50 | 1.32 | 0.32 | 0.04 | 0 | 4.19 | 2.29 |
| 4 | 1.99 | 1.84 | [illegible] | [illegible] | 0.02 | [illegible] | [illegible] | 2.00 | 1.81 | 0.45 | 0.06 | 0.01 | 5.71 | 3.13 | 1.99 | 1.79 | 0.43 | 0.04 | 0 | 5.62 | 3.07 | 2.00 | 1.75 | 0.43 | 0.04 | 0 | 5.62 | 3.07 |
| 5 | 2.98 | 2.74 | [illegible] | [illegible] | [illegible] | [illegible] | 5.16 | 3.00 | 2.72 | 0.68 | 0.08 | 0.01 | 8.18 | 4.48 | 3.00 | 2.70 | 0.66 | 0.06 | 0.01 | 8.37 | 4.57 | 3.00 | 2.65 | 0.66 | 0.08 | 0 | 8.57 | 4.69 |
| 6 | [illegible] | [illegible] | 0.86 | [illegible] | [illegible] | 12.4 | 6.78 | 4.00 | 3.64 | 0.90 | 0.11 | 0.02 | 11.3 | 6.15 | 4.00 | 3.62 | 0.89 | 0.09 | 0 | 11.3 | 6.15 | 4.00 | 3.56 | 0.88 | 0.11 | 0.01 | 11.3 | 6.17 |
| 7 | 4.99 | 4.57 | 1.07 | 0.12 | 0.04 | 15.7 | 8.58 | 5.00 | 4.55 | 1.14 | 0.14 | 0.03 | 13.9 | 7.56 | 4.99 | 4.52 | 1.10 | 0.11 | 0.01 | 13.9 | 7.56 | 5.00 | 4.48 | 1.11 | 0.14 | 0.01 | 14.4 | 7.88 |
| 8 | 4.00 | [illegible] | 0.88 | [illegible] | [illegible] | 12.4 | 6.78 | 4.00 | 3.64 | 0.90 | 0.11 | 0.02 | 10.9 | 5.95 | 4.00 | 3.63 | 0.88 | 0.09 | 0.01 | 11.3 | 6.15 | 6.00 | 5.39 | 1.33 | 0.17 | 0.02 | 17.1 | 9.36 |
| 9 | 3.00 | 2.75 | [illegible] | [illegible] | 0.03 | [illegible] | [illegible] | 3.00 | 2.74 | 0.67 | 0.08 | 0.02 | 8.37 | 4.57 | 3.00 | 2.71 | 0.66 | 0.07 | 0.01 | 8.37 | 4.57 | 7.00 | 6.30 | 1.57 | 0.21 | 0.03 | 20.0 | 10.9 |
| 10 | [illegible] | 1.84 | 0.43 | 0.05 | [illegible] | [illegible] | 3.40 | 2.00 | 1.76 | 0.44 | 0.06 | 0.01 | 5.53 | 3.02 | 2.00 | 1.81 | 0.43 | 0.05 | 0.01 | 5.62 | 3.07 | 7.98 | 7.19 | 1.80 | 0.24 | 0.05 | 22.5 | 12.2 |
| 11 | 1.51 | 1.38 | 0.32 | [illegible] | 0.02 | 4.71 | 2.58 | 1.50 | 1.37 | 0.33 | 0.04 | 0.01 | 4.14 | 2.26 | 1.50 | 1.35 | 0.32 | 0.04 | 0.01 | 4.18 | 2.28 | 7.00 | 6.29 | 1.56 | 0.21 | 0.04 | 20.0 | 10.9 |
| 12 | 1.01 | [illegible] | 0.21 | [illegible] | 0.01 | 3.13 | 1.70 | 1.01 | 0.91 | 0.22 | 0.03 | 0.01 | 2.77 | 1.51 | 1.00 | 0.90 | 0.21 | 0.03 | 0.01 | 2.81 | 1.54 | 6.00 | 5.39 | 1.33 | 0.17 | 0.03 | 16.7 | 9.12 |
| 13 | 0.51 | 0.46 | 0.11 | 0.02 | 0.01 | [illegible] | [illegible] | 0.50 | 0.41 | 0.11 | 0.02 | 0.01 | 1.39 | 0.76 | 0.50 | 0.45 | 0.11 | 0.02 | 0.01 | 1.39 | 0.76 | 5.00 | 4.48 | 1.10 | 0.14 | 0.03 | 13.9 | 7.56 |
| 14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 4.00 | 3.59 | 0.88 | 0.11 | 0.02 | 10.9 | 5.96 |
| 15 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3.00 | 2.67 | 0.66 | 0.08 | 0.01 | 8.57 | 4.69 |
| 16 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2.00 | 1.77 | 0.43 | 0.06 | 0.01 | 5.53 | 3.02 |
| 17 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1.50 | 1.33 | 0.32 | 0.04 | 0.01 | 4.24 | 2.31 |
| 18 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1.00 | 0.88 | 0.21 | 0.03 | 0.01 | 2.75 | 1.50 |
| 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0.50 | 0.44 | 0.10 | 0.02 | 0.01 | 1.41 | 0.77 |
| | | | | | | | | | | | | | Filter 2 | | | | | | | | | | | | | | | |
| 1 | 0.50 | [illegible] | [illegible] | 0.01 | 0 | 1.48 | 0.81 | 0.50 | 0.45 | 0.09 | 0 | 0 | 1.52 | 0.83 | 0.50 | 0.44 | 0.08 | 0 | 0 | 1.68 | 0.92 | 0.50 | 0.43 | 0.08 | 0 | 0 | 1.62 | 0.89 |
| 2 | [illegible] | [illegible] | 0.18 | 0.01 | 0 | 2.95 | 1.61 | 1.00 | 0.90 | 0.17 | 0 | 0 | 3.05 | 1.67 | 1.00 | 0.88 | 0.16 | 0 | 0 | 3.40 | 1.86 | 1.00 | 0.89 | 0.16 | 0.01 | 0 | 3.27 | 1.78 |
| 3 | [illegible] | 1.37 | [illegible] | 0.01 | 0 | 4.50 | 2.46 | 1.49 | 1.34 | 0.27 | 0.01 | 0 | 4.61 | 2.52 | 1.49 | 1.33 | 0.25 | 0.01 | 0 | 5.14 | 2.81 | 1.50 | 1.32 | 0.24 | 0 | 0 | 4.93 | 2.69 |
| 4 | 2.00 | 1.61 | 0.36 | 0.01 | 0 | 6.21 | 3.39 | 1.99 | 1.79 | 0.37 | 0.02 | 0 | 6.21 | 3.40 | 2.00 | 1.78 | 0.34 | 0.01 | 0 | 6.81 | 3.72 | 2.00 | 1.77 | 0.33 | 0.01 | 0 | 6.43 | 3.51 |
| 5 | [illegible] | 2.75 | 0.57 | 0.02 | 0.01 | 9.47 | 5.17 | 3.00 | 2.71 | 0.54 | 0.02 | 0 | 9.47 | 5.18 | 3.00 | 2.67 | 0.51 | 0.01 | 0 | 10.0 | 5.46 | 3.00 | 2.66 | 0.51 | 0.02 | 0 | 10.0 | 5.46 |
| 6 | 4.00 | [illegible] | 0.77 | 0.03 | 0.01 | 12.4 | 6.78 | 4.00 | 3.62 | 0.73 | 0.02 | 0 | 12.8 | 7.02 | 4.00 | 3.59 | 0.69 | 0.02 | 0 | 13.3 | 7.28 | 4.00 | 3.56 | 0.70 | 0.03 | 0.01 | 13.3 | 7.28 |
| 7 | 5.01 | 4.60 | [illegible] | 0.05 | 0.02 | 15.7 | 8.56 | 5.00 | 4.50 | 0.90 | 0.04 | 0.01 | 16.3 | 8.92 | 5.01 | 4.50 | 0.86 | 0.04 | 0.01 | 17.1 | 9.37 | 5.00 | 4.49 | 0.85 | 0.04 | 0 | 17.2 | 9.36 |
| 8 | 4.00 | [illegible] | 0.77 | [illegible] | 0.01 | 12.4 | 6.78 | 4.00 | 3.61 | 0.72 | 0.03 | 0.01 | 12.8 | 7.02 | 4.00 | 3.60 | 0.69 | 0.04 | 0.01 | 13.3 | 7.28 | 6.00 | 5.40 | 1.01 | 0.05 | 0.01 | 20.0 | 10.9 |
| 9 | 3.02 | 2.76 | 0.57 | 0.02 | 0.01 | 9.47 | 5.17 | 3.01 | 2.71 | 0.53 | 0.02 | 0.01 | 9.72 | 5.31 | 3.00 | 2.69 | 0.51 | 0.02 | 0 | 10.0 | 5.46 | 7.00 | 6.31 | 1.18 | 0.07 | 0.02 | 24.0 | 13.1 |
| 10 | 1.99 | 1.80 | 0.36 | 0.01 | 0.01 | 6.21 | 3.39 | 2.00 | 1.80 | 0.35 | 0.02 | 0 | 6.43 | 3.51 | 2.00 | 1.79 | 0.34 | 0.01 | 0 | 6.67 | 3.64 | 8.00 | 7.22 | 1.37 | 0.09 | 0.02 | 27.7 | 15.1 |
| 11 | 1.50 | 1.36 | 0.28 | 0.01 | 0 | 4.73 | 2.59 | 1.49 | 1.34 | 0.26 | 0.01 | 0 | 4.74 | 2.59 | 1.50 | 1.35 | 0.25 | 0.01 | 0 | 5.00 | 2.73 | 7.00 | 6.32 | 1.19 | 0.08 | 0.02 | 24.0 | 13.1 |
| 12 | 1.00 | 0.90 | 0.18 | 0.01 | 0 | 3.11 | 1.70 | 1.00 | 0.90 | 0.18 | 0 | 0 | 3.19 | 1.74 | 1.00 | 0.89 | 0.16 | 0 | 0 | 3.33 | 1.82 | 6.00 | 5.41 | 1.01 | 0.06 | 0.01 | 20.0 | 10.9 |
| 13 | 0.51 | 0.45 | 0.09 | 0 | 0 | 1.58 | 0.86 | 0.50 | 0.44 | 0.09 | 0 | 0 | 1.59 | 0.87 | 0.50 | 0.44 | 0.08 | 0 | 0 | 1.66 | 0.91 | 5.00 | 4.50 | 0.84 | 0.04 | 0.01 | 17.2 | 9.36 |
| 14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 4.00 | 3.60 | 0.67 | 0.03 | 0.01 | 13.8 | 7.57 |
| 15 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 3.00 | 2.70 | 0.49 | 0.02 | 0 | 10.3 | 5.62 |
| 16 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 2.00 | 1.79 | 0.32 | 0.01 | 0 | 6.79 | 3.71 |
| 17 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1.50 | 1.34 | 0.24 | 0.01 | 0 | 5.06 | 2.77 |
| 18 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 1.00 | 0.89 | 0.15 | 0 | 0 | 3.37 | 1.83 |
| 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0.50 | 0.45 | 0.08 | 0 | 0 | 1.70 | 0.93 |

(Continued)

Note: 0 values are <0.01.

Table 2 (Concluded)

| | Before Surging | | | | | | | After 1st Surging | | | | | | | After 2d Surging | | | | | | | After 3d Surging | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Piezometric Head, ft | | | | | Discharge gpm | | Piezometric Head, ft | | | | | Discharge gpm | | Piezometric Head, ft | | | | | Discharge gpm | | Piezometric Head, ft | | | | | Discharge gpm | |
| Step | $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ | Total | Per ft Screen | $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ | Total | Per ft Screen | $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ | Total | Per ft Screen | $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ | Total | Per ft Screen |
| | | | | | | | | | | | | | | Filter 3 | | | | | | | | | | | | | | |
| 1 | 0.51 | 0.46 | 0.10 | 0 | 0 | 1.52 | 0.83 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | None Taken | | | | | 3.08 | 1.68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 3 | 1.50 | 1.35 | [illegible] | 0 | 0 | 4.50 | 2.46 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 4 | [illegible] | 1.81 | 0.40 | 0.01 | 0 | 6.00 | 3.28 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 5 | 3.00 | 2.7[illegible] | [illegible] | .01 | 0 | 9.23 | 5.04 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 6 | 4.00 | 3.67 | [illegible] | 0.22 | 0 | 12.0* | 6.56 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 7 | 5.01 | 4.60 | 1.24 | 0.37 | 0.01 | 15.6* | 8.53 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 8 | 4.00 | 3.67 | 1.00 | .30 | 0.01 | 12.0 | 6.56 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | 3.00 | 2.76 | 0.73 | 0.21 | 0 | 9.23 | 5.04 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 10 | 2.00 | 1.80 | 0.45 | 0.14 | 0 | 6.21 | 3.39 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 11 | 1.51 | 1.38 | 0.3[illegible] | 0.17 | 0 | 4.66 | 2.55 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12 | 1.00 | 0.91 | 0.23 | 0.06 | 0 | 3.13 | 1.71 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 13 | 0.50 | 0.46 | 0.11 | 0.03 | 0 | 1.56 | 0.86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 14 | 0.50 | 0.45 | 0.10 | 0.03 | 0 | 1.55 | 0.85 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 15 | 1.00 | 0.90 | 0.21 | 0.05 | 0 | 3.13 | 1.71 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 16 | 1.50 | 1.35 | 0.32 | 0.08 | 0 | 4.73 | 2.59 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 17 | 2.00 | 1.81 | 0.44 | 0.11 | 0 | 6.32 | 3.45 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 18 | 3.00 | 2.73 | 0.72 | 0.20 | 0 | 9.47 | 5.17 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 19 | 4.00 | 3.64 | 1.06 | 0.31 | 0 | 12.4* | 6.78 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 20 | 4.98 | 4.53 | 1.22 | 0.43 | 0.04 | 16.3* | 8.92 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 21 | 0.50 | 0.45 | 0.10 | 0.02 | 0 | 1.77 | 0.96 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 22 | 1.00 | 0.84 | 0.20 | 0.04 | 0 | 3.42 | 1.87 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 23 | 1.49 | 1.33 | 0.30 | 0.07 | 0 | 5.15 | 2.81 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 24 | 2.00 | 1.89 | 0.43 | 0.10 | 0 | 7.07 | 3.86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 25 | 3.02 | 2.71 | 0.73 | 0.2[illegible] | 0.01 | 10.3* | 5.62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 26 | 4.02 | 3.61 | 1.32 | 0.45 | 0.07 | 13.3* | 7.30 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

* Flow turned cloudy. Foundation sand penetrating filter gravel. Most of the sand collecting on bottom of well. Some sand in effluent.

Table 3

Effects of Clogging on Head Loss Through Well Screen

| Condition of Well Screen | Slot Area Unclogged % | Discharge per Foot of Well Screen gpm/ft | Head Loss ft |
|---|---|---|---|
| No filter | 100 | 19.7 | <0.005 |
| At the conclusion of tests with filter 1 | 20 | 4.17 | 0.005 |
| | | 7.55 | 0.010 |
| | | 13.1 | 0.020 |
| | | 19.7 | 0.030 |
| At the conclusion of tests with filter 2 | 50 | 3.64 | <0.005 |
| | | 6.15 | 0.005 |
| | | 11.6 | 0.010 |
| | | 19.7 | 0.020 |
| At the conclusion of tests with filter 3 | 70 | 3.71 | <0.005 |
| | | 8.94 | <0.005 |
| | | 19.7 | 0.005 |

Table 4

Summary of Surging Data

| Filter No. | Surging Cycle | Cumulative Depth of Material in Well at Intervals of 10 Strokes with Plunger,* cm: 10 Strokes | 20 Strokes | 30 Strokes | 40 Strokes | 50 Strokes | Dry Wt of Material in Well at End of a Surging Cycle, lb | Volume of Surged Material in Well at End of a Surging Cycle: pt | pt/ft well | $D_{15}$ of Surged Material mm | Percent Foundation Sand in Surged Material | Volume of Foundation Sand in Surged Material pt/ft well |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 4.8 | 6.3 | 9.6 | 12.6 | 14.2 | 17± | 9.24 | 5.05 | 0.71 | 3 | 0.15 |
| | 2 | 2.8 | 4.0 | 4.6 | 6.4 | 7.6 | 9.01 | 4.90 | 2.68 | 0.32 | 18 | 0.48 |
| | 3 | 1.0 | 1.9 | 2.5 | 3.3 | 3.3 | 4.78 | 2.60 | 1.42 | 0.20 | 24 | 0.34 |
| | 4 | 0.2 | 0.7 | 1.1 | 1.1 | 1.3 | 3.21 | 1.74 | 0.95 | 0.18 | 32 | 0.30 |
| 2 | 1 | 2.5 | 5.1 | 6.9 | 8.7 | 10.0 | 14.30 | 7.78 | 4.24 | 0.30 | 18 | 0.76 |
| | 2 | 0.6 | 1.2 | 1.8 | 2.2 | 2.7 | 4.53 | 2.46 | 1.34 | 0.17 | 51 | 0.68 |
| | 3 | 0.5 | 0.9 | 1.1 | 1.5 | 1.9 | 3.27 | 1.78 | 0.97 | 0.15 | 60 | 0.58 |
| | 4 | 0.4 | 0.9 | 1.4 | 1.8 | 2.1 | 4.11 | 2.23 | 1.22 | 0.14 | 71 | 0.87 |
| 3 | 1 | 7.6 | 14.4 | -- | -- | -- | 17.83 | 9.68 | 5.29 (13.2)** | 0.13 | 87 | 4.61 (11.5)** |

* Plunger consists of a 7-in.-diam rubber disk held between steel plates mounted on a 2-in.-diam steel rod. Depth in well obtained by sounding top of material with a rod. Plunger moved manually.

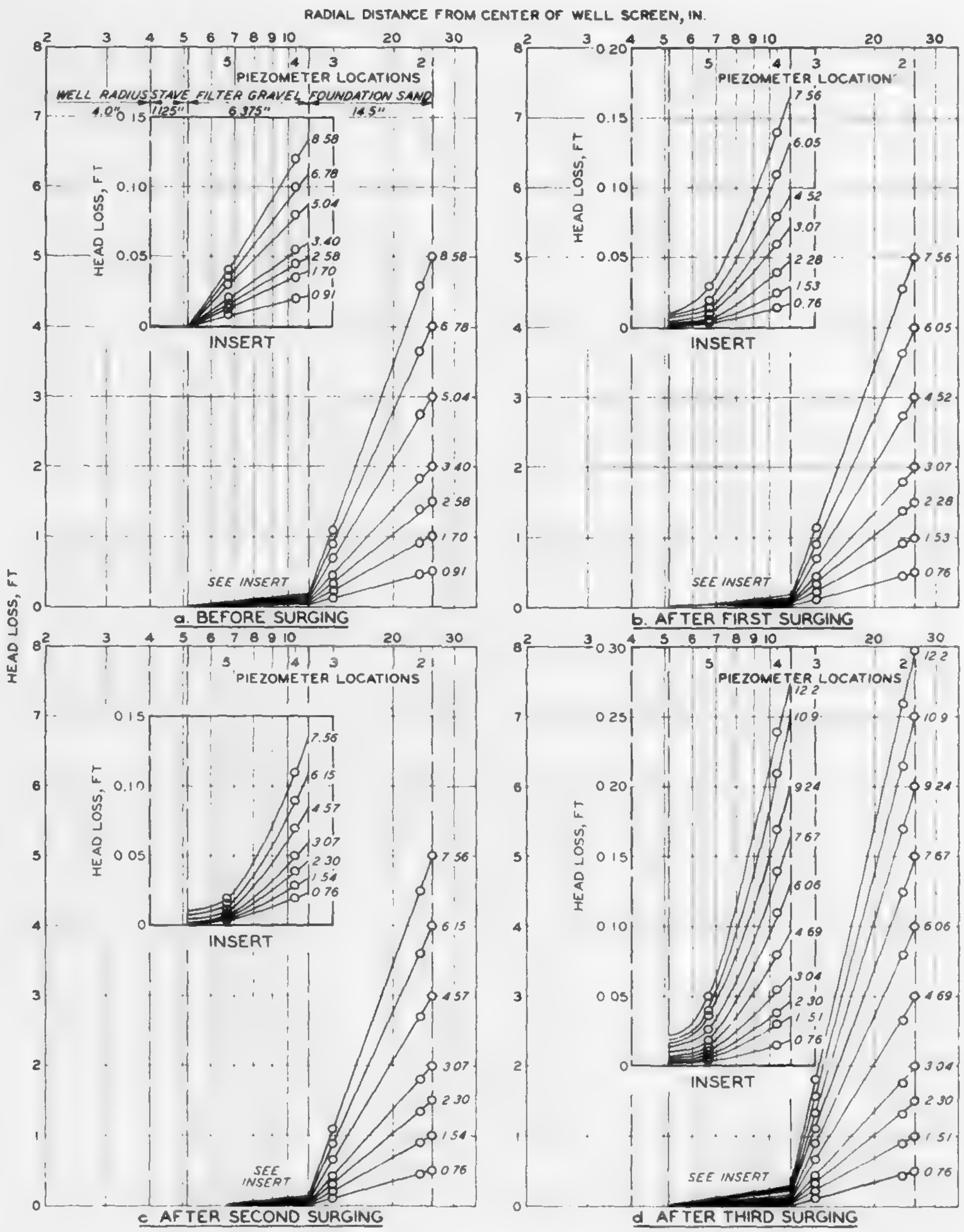
** Estimated for full cycle.

Table 5

Rates of Sand Piping Through Filter Gravel

| Filter No. | Piezometric Head, ft $h_1$ | $h_2$ | $h_3$ | $h_4$ | $h_5$ | Flow, gpm Total | Per ft Screen | Sand Infiltration Through Filter Gravel Duration min | Volume pt | Rate pt/hr/ft Screen | Hydraulic Gradient, i at Sand-Filter Interface |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -- | -- | -- | -- | -- | -- | -- | -- | Trace | -- | 9.8 |
| 2 | -- | -- | -- | -- | -- | -- | -- | -- | Trace | -- | 10.6 |
| 3 | 1.00 | 0.90 | 0.21 | 0.07 | 0 | 3.36 | 1.84 | 15.0 | Trace | -- | 1.3 |
| | 1.00 | 0.89 | 0.20 | 0.04 | 0 | 3.43 | 1.87 | 6.0 | Trace | -- | 1.3 |
| | 2.00 | 1.84 | 0.45 | 0.15 | 0.01 | 6.54 | 3.57 | 15.0 | 0.074 | 0.164 | 2.5 |
| | 2.00 | 1.79 | 0.43 | 0.11 | 0.01 | 7.07 | 3.86 | 5.0 | Trace | -- | 2.5 |
| | 2.99 | 2.70 | 0.72 | 0.26 | 0.02 | 10.0 | 5.46 | 15.0 | 0.643 | 1.40 | 3.6 |
| | 3.02 | 2.71 | 0.68 | 0.26 | 0.01 | 10.3 | 5.62 | 13.0 | 0.480 | 1.20 | 3.7 |
| | 4.00 | 3.62 | 1.00 | 0.41 | 0.05 | 12.9 | 7.05 | 12.0 | 5.12 | 14.0 | 4.7 |
| | 4.02 | 3.61 | 0.97 | 0.46 | 0.07 | 13.3 | 7.30 | 5.0 | 2.92 | 19.3 | 4.8 |

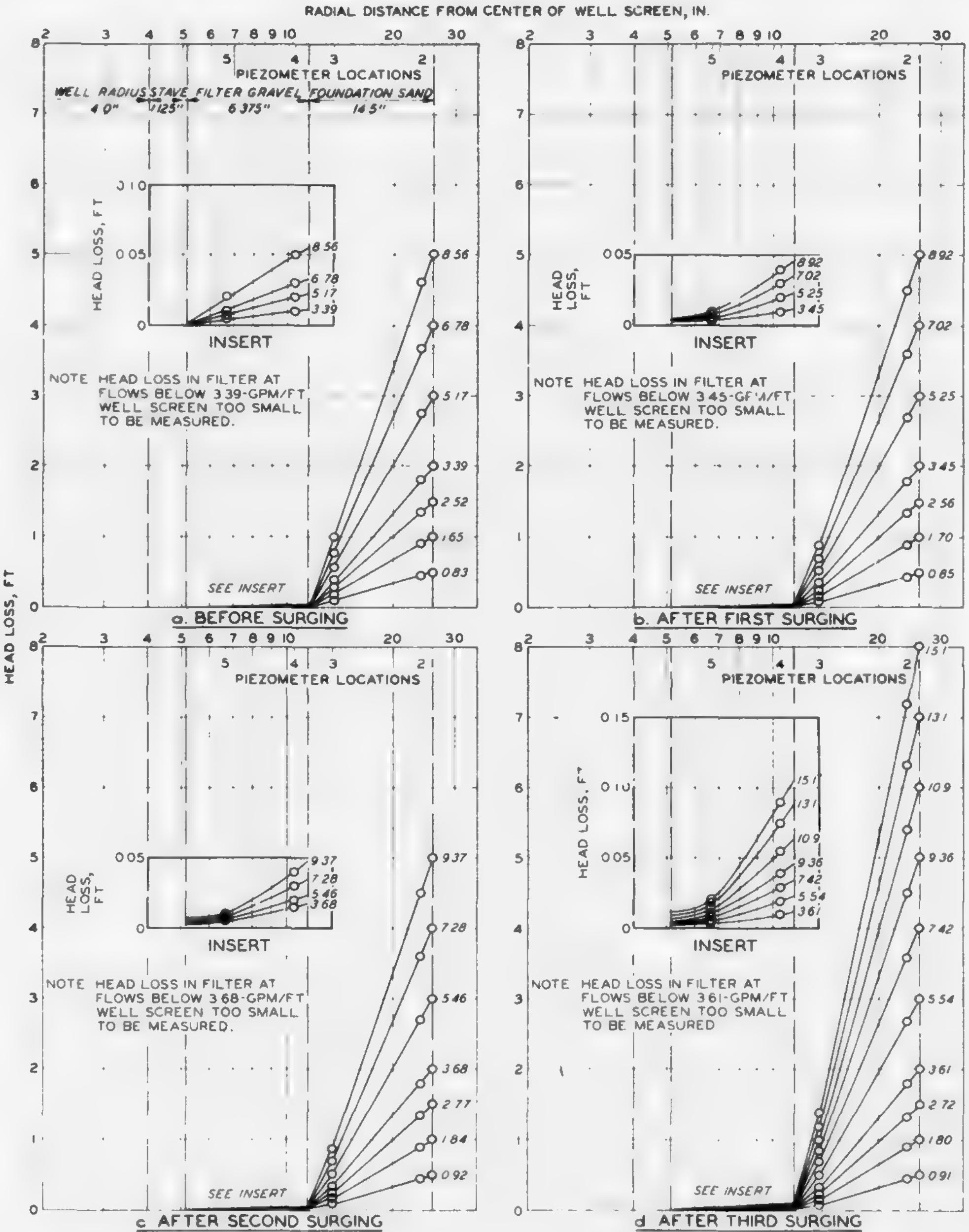
Note: $i = \dfrac{h_2 - h_3}{R\ell n(r_2/r_3)}$ , where R is the radius to sand-gravel interface.




NOTE: FIGURES BY CURVES ARE DISCHARGES IN GPM/FT OF WELL SCREEN
HEAD LOSS AT OUTER FACE OF SCREEN INTERPOLATED FROM INDEPENDENT TESTS ON CLOGGED WELL SCREEN.

**HEAD LOSS DISTRIBUTION IN SAND AND GRAVEL**

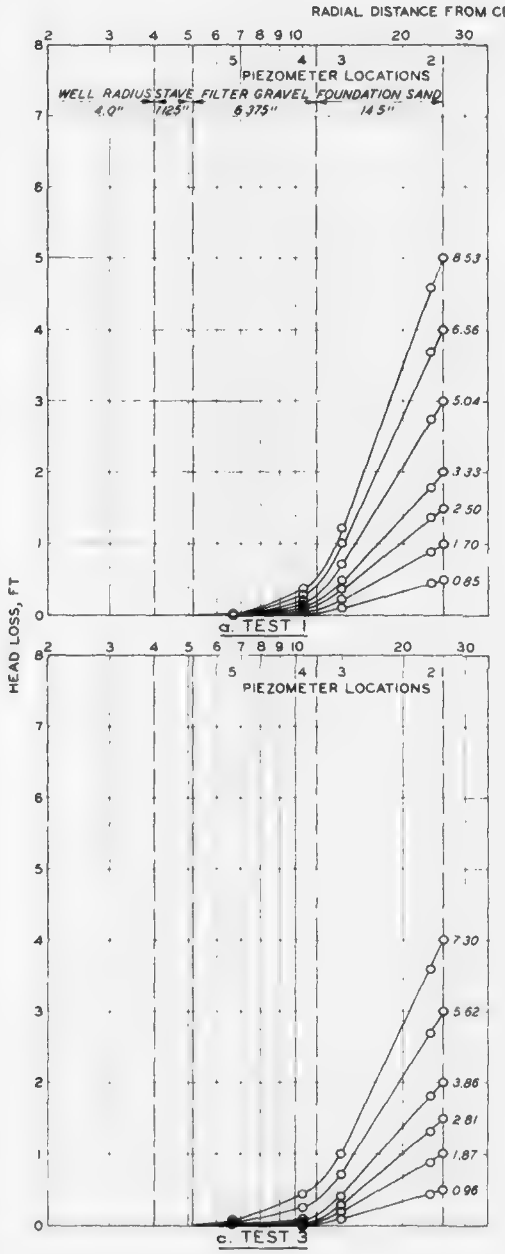
FILTER 1




NOTE FIGURES BY CURVES ARE DISCHARGES IN GPM/FT OF WELL SCREEN
HEAD LOSS AT OUTER FACE OF SCREEN INTERPOLATED FROM INDEPENDENT TESTS ON CLOGGED WELL SCREEN.

**HEAD LOSS DISTRIBUTION IN SAND AND GRAVEL**

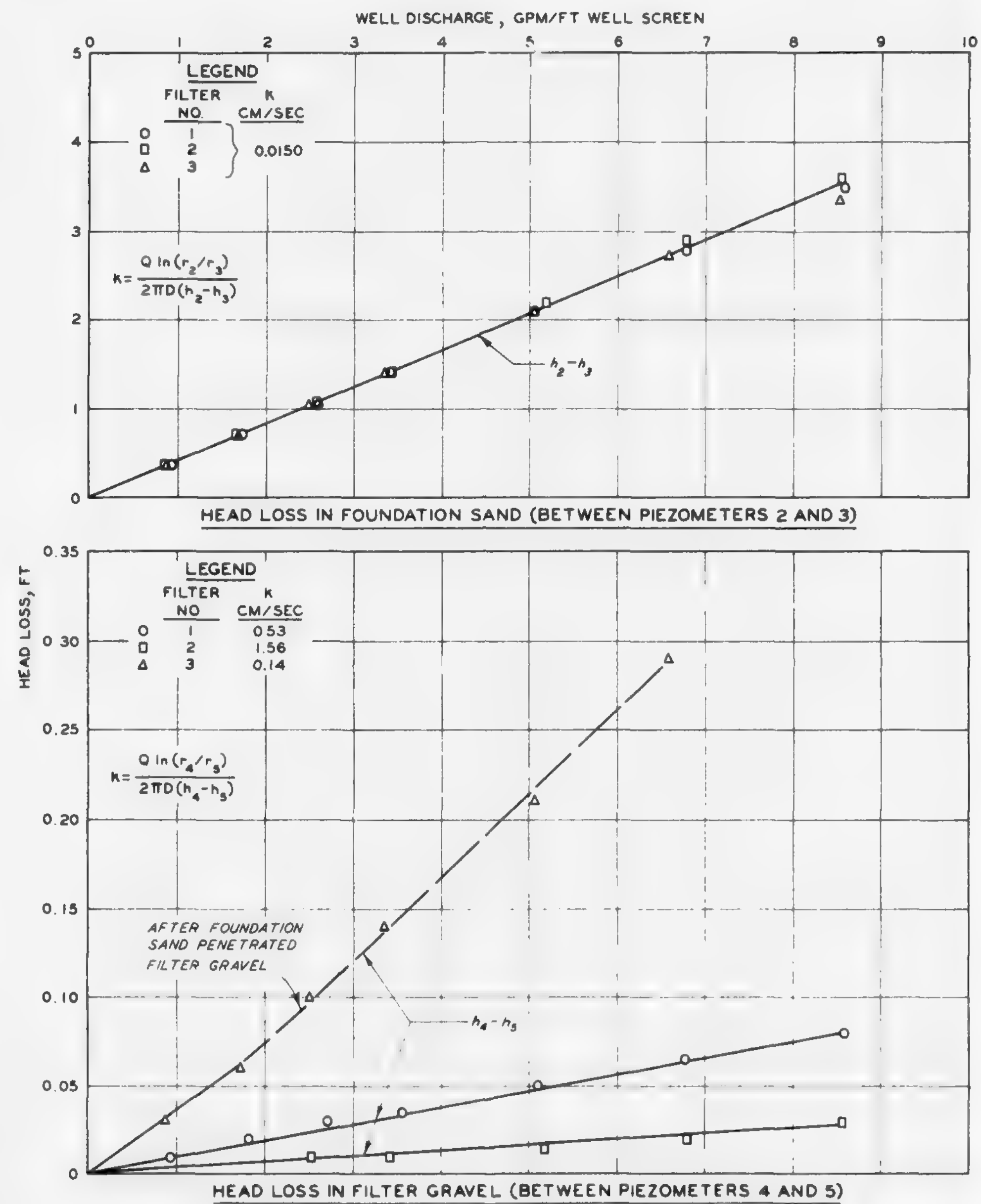
FILTER 2




NOTE FIGURES BY CURVES ARE DISCHARGES IN GPM/FT OF WELL SCREEN

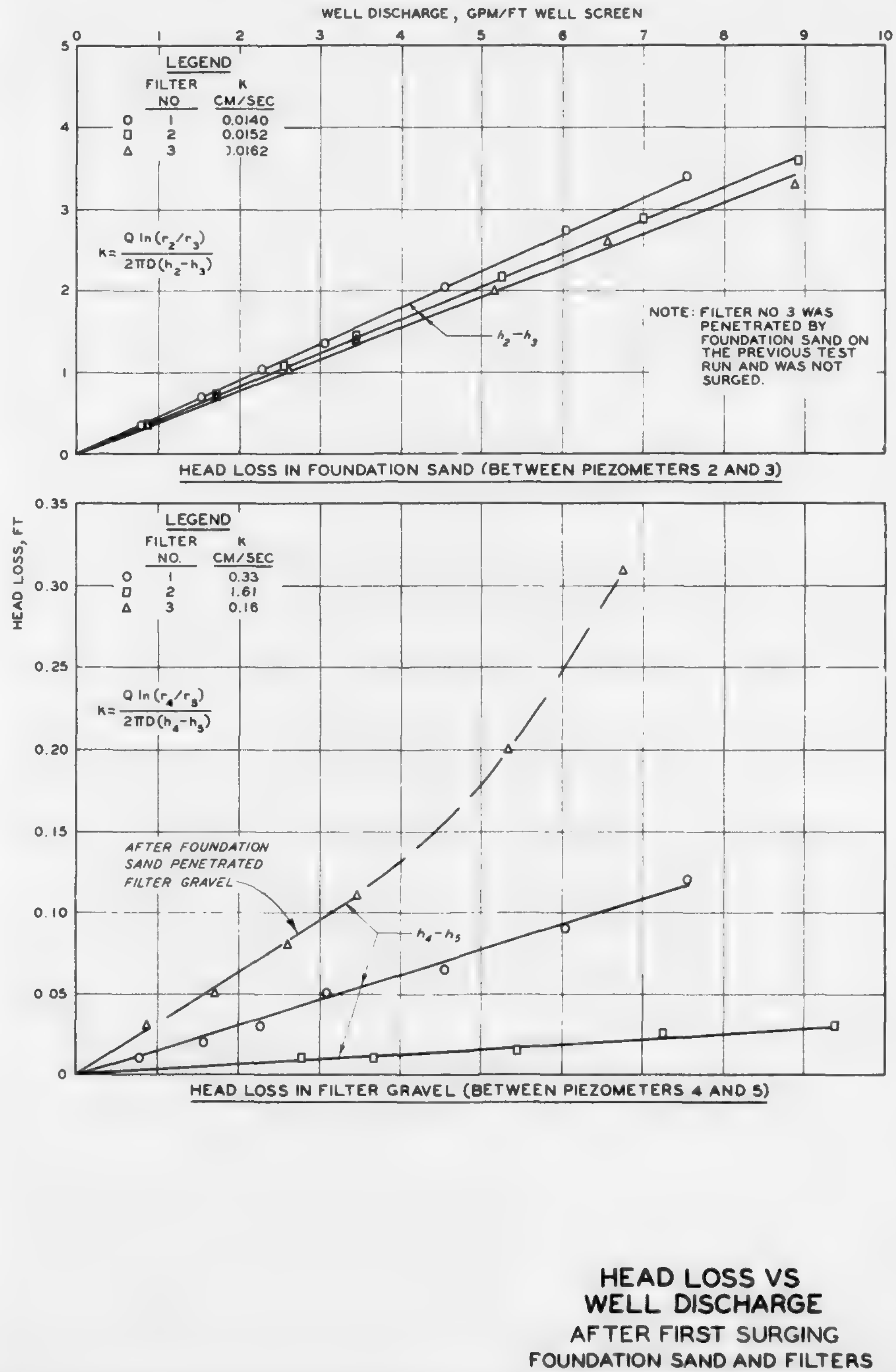
**HEAD LOSS DISTRIBUTION IN SAND AND GRAVEL**

FILTER 3




**HEAD LOSS VS WELL DISCHARGE**
BEFORE SURGING
FOUNDATION SAND AND FILTERS

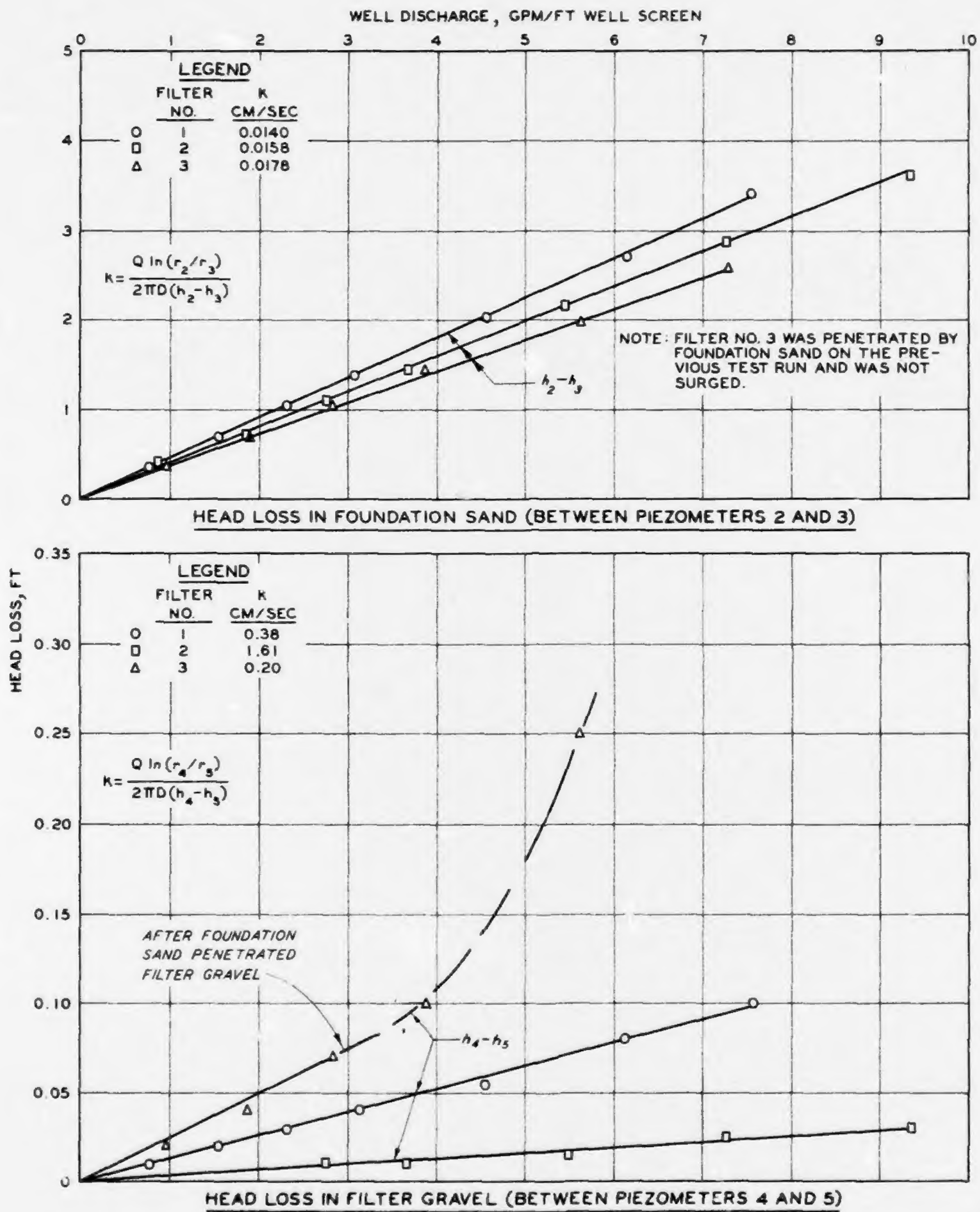
PLATE 4




**HEAD LOSS VS WELL DISCHARGE**

AFTER FIRST SURGING
FOUNDATION SAND AND FILTERS

PLATE 5

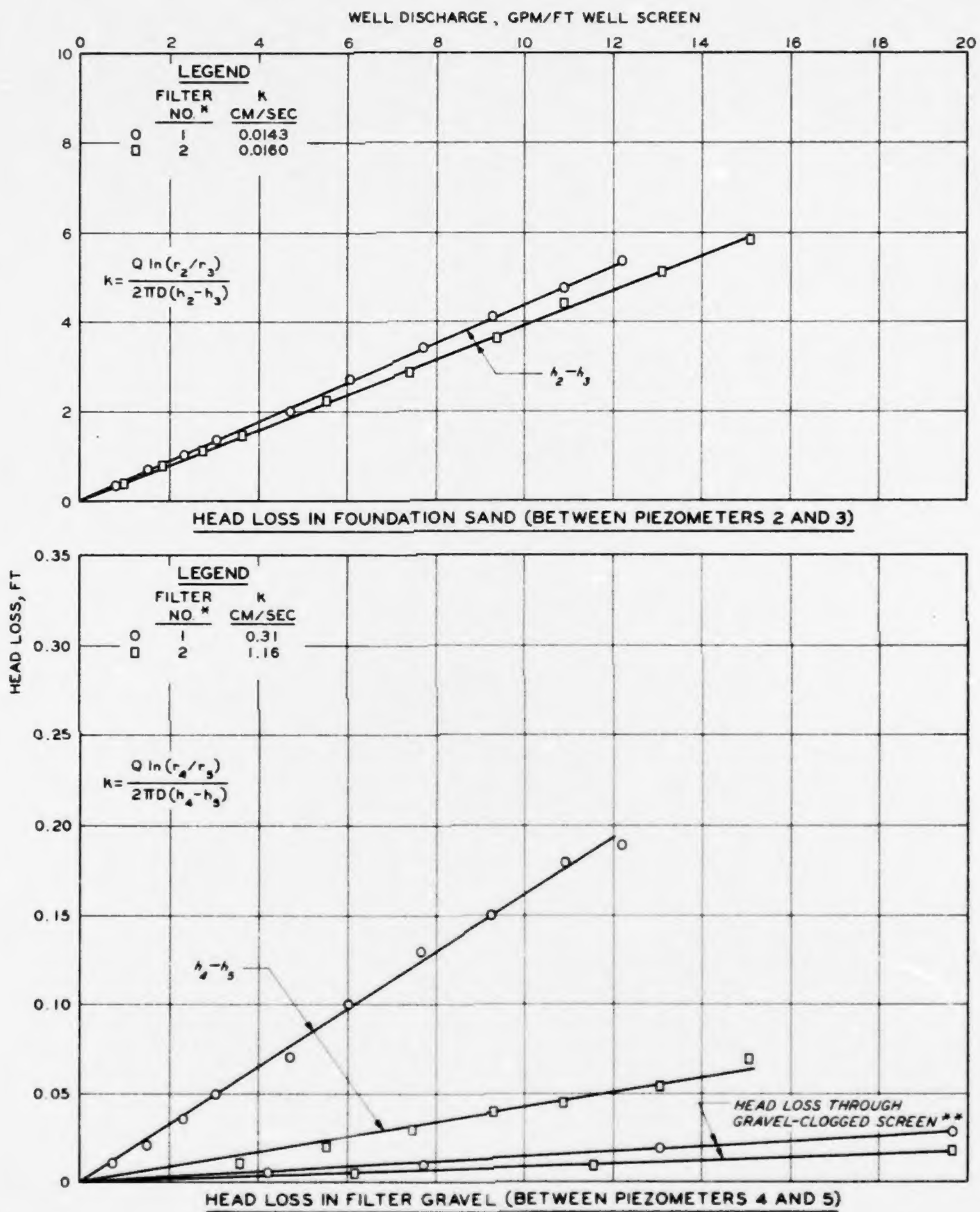



**HEAD LOSS VS WELL DISCHARGE**

AFTER SECOND SURGING

FOUNDATION SAND AND FILTERS

PLATE 6




NOTE: * NO TEST PERFORMED WITH FILTER NO. 3.

** HEAD LOSS THROUGH GRAVEL-CLOGGED SCREEN MEASURED IN SEPARATE TESTS WITHOUT FILTER GRAVEL AND SAND IN TANK.

**HEAD LOSS VS WELL DISCHARGE**

AFTER THIRD SURGING

FOUNDATION SAND AND FILTERS

Unclassified

Security Classification

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13. ABSTRACT Laboratory tests to obtain data on performance of gravel filters with gradations such as might result from segregation of a typical specified filter material were conducted using a typical slotted wood well screen, three filter gravel gradations (filters 1, 2, and 3), and a fine, uniform Mississippi River sand base material. Filter 1 had the average gradation of the normally specified filter gravel for relief wells in the Alton to Gale, Ill., project; filters 2 and 3 represented gradations that might result from segregation of filter 1. Performance of the filters was evaluated by comparing their effectiveness in preventing piping of the foundation sand into the well, changes in head loss in the well screen and filter due to migration of materials, and effectiveness in preventing loss of sand and filter fines through well pipe perforations during surging. Data obtained included piezometric head distribution in foundation sand and filter gravel; hydraulic head losses in sand, gravel, and well screen; rate of sand infiltration; and loss of materials into the well during surging. No piping of foundation sand occurred through the gravel of filters 1 and 2 under a maximum hydraulic head of 8 ft. At this head, well discharge in the laboratory tests was comparable to maximum well flows specified in field pumping tests. Rate of sand piping through the gravel of filter 3 increased with increasing well discharge. All filters were penetrated to varying degrees by foundation sand during surging. Hydraulic head losses in the screen and filter gravel for all filters were significantly less than would account for the reduced efficiency observed for wells along the Mississippi River. It is concluded that variation in gradation of filter gravel such as might be induced by segregation may lead to failure of the well due to piping but it is not a major factor in causing a reduction in well efficiency due to clogging of the filter gravel with foundation sand.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Filters (Seepage control) | | | | | | |
| Gravel | | | | | | |
| Relief wells | | | | | | |
| Well filters | | | | | | |
| Well screens | | | | | | |

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